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Rock weathering experiments with microbial ecosystems under Archean conditions

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During the Archean eon (4.0–2.5 Ga), microbial ecosystems dominated the biosphere under environmental conditions markedly different from today, including lower solar luminosity, an anoxic atmosphere, and different geodynamic. Despite these differences, key surface characteristics such as the presence of liquid water, oceans, similar pH conditions, and carbonate precipitation were already established.

Life is now recognized as a major driver of surface processes, profoundly influencing weathering, soil formation, and global biogeochemical cycles. However, the extent to which early microbial life modified its environment during the Archean remains poorly constrained. How did primitive ecosystems interact with rocks, water, and the atmosphere? To address this question, we performed controlled rock weathering experiments under simulated Archean conditions, both in the presence and absence of microbial communities. Weathering represents a critical interface among the lithosphere, hydrosphere, atmosphere, and biosphere, providing a direct pathway for biological influence on mineral alteration and elemental cycling.

We model the four main Earth compartments under Archean conditions:

- air: based on paleosol data (no O_2, high CO_2).
- rock: representative Archean rocks were selected 'komatiites, basalts and tonalite-trondhjemite-granodiorite).
- water: we sample the deep water (80m) from the Lake Pavin (France), a meromictic maar lake. Due to its morphology this lake does not allow the water to mix through the water column. It has anoxic conditions below 60m depth and high concentrations of dissolved Fe, considered as an analog of the Archean.
- life: we sample the preexisting microbial community (methanotrophs, methanogen, sulfur-oxidizing bacteria, nitrate-reducing bacteria...) in the deep Lake Pavin water, ensuring its sustainability.

A major experimental challenge was the prevention of atmospheric and biological contamination. We developed a protocol and performed all experiments in a glovebox housed within an ecotron (CEREEP Ecotron Île-de-France). We conducted 3 sets of experiments: 1) biotic experiments with rocks pre-incubated in the lake for six months to allow biofilm development, 2) biotic experiments without prior rock incubation, 3) abiotic experiments to differentiate the abiotic processes.

We show how the dissolved water composition, atmospheric composition, and microbial diversity evolved. The results will help to understand how life and weathering have regulated Earth's surface environments during the Archean.