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Mineralogical Controls on Microbial Viability and Growth: Implications for MEOR and Subsurface Carbon Cycling

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The efficiency of Microbial Enhanced Oil Recovery (MEOR) and organic matter preservation are fundamentally governed by mineral–microbe interactions. While MEOR can increase hydrocarbon yield by up to 30%, the lithological environment exerts a decisive but poorly constrained influence on microbial survival and metabolic activity. This study resolves how key mineral phases — clays, carbonates, and silicates — modulate the growth and viability of MEOR-relevant bacterial species, providing mechanistic insight into their biogeochemical roles.

We reveal a complex, non-linear relationship between mineral concentration and microbial health, evidenced by sharp contrasts between suspended broth growth (OD_{600}) and colony viability (CFU). Illite emerged as a uniquely probacterial phase: despite severely restricting suspended growth (OD 0.21–0.06 vs. blank 1.296), it consistently enhanced viability, yielding CFU counts (388–615) far exceeding the blank (230). This decoupling indicates illite creates a protective micro-environment that shields cells from lethal stress. Albite similarly supported viability, likely through the release of bioavailable Na, Ca, and Si.

In contrast, calcite and quartz exhibited strong antibacterial effects. Despite maintaining moderate turbidity (OD 0.71–1.02), calcite reduced CFU counts to near-negligible levels (18–23), suggesting interference with colony-forming capacity rather than bulk growth suppression. Kaolinite and bentonite displayed dose-dependent dual behaviour: at low concentrations (25 mg) they supported adhesion and surface protection, enhancing viability above the blank, while at higher concentrations (125 mg) inhibitory effects — likely nutrient sequestration or osmotic imbalance — dominated.

Two-way ANOVA with post-hoc comparisons confirmed that both mineral species and concentration independently and interactively shape bacterial response. These results demonstrate that surface area, cation-exchange capacity, and hydration structure determine whether a mineral phase catalyses or suppresses microbial processes.

By connecting nanoscale mineral–microbe interfaces to ecosystem-scale outcomes, this work provides a predictive framework for targeting MEOR deployment in geologically complex reservoirs and advances understanding of how mineralogy governs organic carbon stabilization and turnover in the subsurface.