

Mineral-Facilitated Horizontal Gene Transfer: A Geological Driver of Bacterial Evolution and Antibiotic Resistance Propagation

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Unlike higher organisms, bacteria can acquire extracellular DNA and adapt to stress. We have explored the concept of mineral-facilitated horizontal gene transfer (HGT) in which sedimentary minerals act as reservoirs for extracellular DNA, enabling genetic exchange to bacteria across time and space. DNA rapidly degrades in aqueous environments, but adsorbed to mineral surfaces the DNA can be preserved for up to 2 Ma¹. Currently there is approximately 0.45 Gt extracellular DNA stored in the top 10 cm of ocean floor sediments². Many bacteria prefer to colonize on mineral surfaces which increase the chance of a bacteria to encounter mineral preserved extracellular DNA.

We combined microbiology and interfacial geochemistry and demonstrate that two common natural competent soil bacteria can incorporate mineral adsorbed 60 bp DNA fragments (*Acinetobacter baylyi*)³ and larger antibiotic resistance encoding genes (*Bacillus subtilis*)⁴. We show that mineral surface charge density and active site availability influence gene transfer frequencies, bacterial viability, biofilm formation, and subsequent amplification via cell division. While highly charged minerals tend to reduce bacterial viability, they do not prevent transformation, suggesting that DNA-mineral interactions are critical determinants. Once biofilms form, the incorporated DNA is amplified independent of mineral surface properties, as long as there is an evolutionary pressure for maintaining the gene.

Our findings reinforce the role of sediments as evolutionary hotspots and suggest that mineral-facilitated horizontal gene transfer could impact bacterial adaptations and for propagation of antibiotic resistance in natural environments. From a geoscience perspective, recognizing minerals as active mediators of genetic exchange has broad implications for evolutionary biology, sedimentary geochemistry, and microbial ecology. Furthermore, this work emphasizes the need for mitigation strategies targeting biofilm formation to curb the spread of antibiotic resistance in sedimentary systems.

References

1 Kjær, K. H., et al. A 2-Million-Year-Old Ecosystem. Nature 2022, 612

2 Torti, A. et al. Origin, Dynamics, and Implications of