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Molecular-scale insights into DNA-mineral interactions: Implications for sedimentary DNA preservation

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Sedimentary ancient DNA (sedaDNA) is an increasingly powerful archive for paleoenvironmental reconstruction, capturing ecological transitions ranging from mammoth steppe collapse to millennial-scale marine biodiversity shifts [1]. Yet sedaDNA records are spatially heterogeneous: abundant in organic-rich, cold environments but often absent in humid, quartz-dominated settings despite comparable expected biodiversity. Taking interfacial geochemistry and biomolecule-mineral interactions into account, the mineralogical and chemical properties of the depositional environment are expected to play a central role in DNA preservation [2,3]. Currently, we lack a predictive framework for identifying sediments with high extracellular DNA preservation potential, and extraction strategies remain largely empirical. Thus, it is unclear whether sedaDNA absence reflects true absence, postdepositional degradation or incomplete recovery of mineral-bound DNA. Previous studies have shown that strong adsorption of DNA on minerals can enhance its stability during burial and transport, whereas weak binding promotes desorption and subsequent loss [4].

In this study we aim to determine which properties of DNA-mineral interactions affect DNA adsorption strength, mobility and susceptibility of degradation. We quantify DNA-mineral adhesion energies using Chemical Force Microscopy as a function of mineral surface composition and solution chemistry. Atomic Force Microscopy probes functionalized with 100 bp DNA fragments were used to measure interaction forces with mineral surfaces. Our results show that mineralogy, pH, salinity, and DNA conformation strongly influence adhesion strength and highlight that the chemical conditions of the depositional environment will impact the preservation of adsorbed DNA and the DNA-mineral complex.

These molecular-scale insights clarify geochemical mechanistic controls on sedaDNA taphonomy, preservation potential, and hints at ways to optimize extraction protocols.

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