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DNA polymer length controls adsorption and preservation against enzymatic hydrolysis at mineral surfaces

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Long-term DNA preservation in the environment has profound implications for reconstructing past ecosystems and understanding key biogeochemical processes ranging from phosphorus cycling to horizontal gene transfer. While free DNA in solution decays rapidly, sediment-bound DNA can persist for up to two million years, highlighting the crucial role of mineral surface adsorption in its exceptional preservation.[1,2] Environmental degradation yields a heterogeneous distribution of DNA polymer lengths, with exclusive preservation of small sequences (typically <100 bp) over long timescales.[3] As a polyelectrolyte, DNA polymers of varying lengths could affect the adsorption dynamics, ultimately influencing its long-term persistence. Despite extensive research on the influence of mineral properties and solution chemistry, the role of DNA polymer length—particularly at environmentally relevant short-length scales—on DNA adsorption to minerals remains unresolved, limiting our ability to utilize the large genetic information pool in the environment efficiently.

In this study, the impact of DNA polymer length on adsorption to diverse mineral surfaces (clays, Fe-(III)oxy-hydroxides, and hydroxyapatite) and the resulting effect on DNA protection against enzymatic DNA hydrolysis is investigated. Through a series of controlled batch experiments, we assessed the adsorption (rates, extent and competition) and the subsequent stability of adsorbed DNA in the presence of model endo- and exonucleases, using qPCR and gel electrophoresis. Our findings demonstrate that DNA polymer length significantly influences adsorption, with shorter polymers exhibiting a higher adsorption capacity than longer polymers in competitive systems. Enzymatic hydrolysis experiments further support this behaviour, revealing a strong size dependency in DNA preservation, with shorter sequences more resistant to degradation.

Our work provides an experimental validation for the long-term persistence exclusivity of short DNA sequences in the soil and sedimentary environments, emphasizing that both polymer length and mineral surface adsorption are critical in determining long-term persistence. These insights advance our understanding of DNA preservation mechanisms and have important implications for recovering and interpreting ancient DNA in geochemical and archaeological contexts.

References

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