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Mineralogical and redox controls on sedimentary DNA adsorption and preservation

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Sedimentary ancient DNA provides a valuable archive for reconstructing past ecosystems, yet its preservation is highly variable and strongly controlled by mineral-molecule interactions. While free DNA degrades rapidly, mineral-associated DNA can persist over geological timescales, indicating that sediment chemistry and redox conditions govern long-term stabilization. Anoxic environments, in particular, may enhance preservation by limiting enzymatic degradation and modifying the reactivity of mineral surfaces, especially iron-bearing mineral phases. However, the mechanisms controlling adsorption, retention, and redistribution of environmentally relevant short DNA fragments (generally considered ancient DNA) remain poorly constrained, complicating interpretation of paleoenvironmental genetic records.

This project investigates how mineralogy and geochemical conditions influence DNA adsorption and persistence using controlled laboratory experiments combined with physicochemical characterization. Representative minerals common in sediments - including clays (montmorillonite and kaolinite), iron oxyhydroxides (goethite and ferrihydrite), and calcium phosphates - are incubated (from several hours to days) with DNA fragments of different lengths (99 bp, 1000 bp, and 20,000 bp). Adsorption kinetics and adsorption capacity are quantified using solution-phase DNA concentration measurements (UV/fluorescence spectroscopy and qPCR). DNA fragment integrity and size distribution are evaluated using gel electrophoresis. Surface charge evolution during binding is determined through zeta potential measurements, while mineralogical stability and surface properties are identified by X-ray diffraction and surface area analyses. Experiments are performed under oxic and anoxic conditions across gradients of pH, ionic strength, and background cations to determine binding mechanisms and potential desorption.

The study aims to determine (i) how DNA fragment size controls adsorption affinity and stability, (ii) how mineral surface charge, solution chemistry, and redox state of mineral surface (particularly iron-bearing phases and associated porewater conditions- oxic vs anoxic) regulate binding mechanisms, and (iii) whether mineral-bound DNA can be redistributed within sediments. By linking adsorption behavior with sediment properties, our work evaluates whether DNA preservation reflects original biodiversity or post-depositional geochemical filtering.

Our work provides a mechanistic framework to interpret fragment-length biases in sedimentary DNA records across environmentally relevant geochemical conditions, improving the reliability of genetic archives in archaeological and paleoenvironmental reconstructions.