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Modern decay as a window into the fossil record: Microbial dynamics and biomineralization during fish decomposition

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The study of fossils has long supported the view that anoxic or anaerobic conditions are essential for fossilization, primarily because oxygen-poor environments limit the activity of scavengers and sediment-dwelling bioturbators, enhancing the likelihood that soft tissues can persist long enough to undergo mineral stabilization. However, emerging fossil research suggests that anaerobic microorganisms are central to the preservation of biomolecules in fossils, actively contributing to fossilization processes [1]. Microorganisms are known to mediate organic matter degradation and generate chemical gradients capable of driving mineral precipitation [2]; however, direct links between microbial metabolism and preservation mechanisms remain underexplored.

This study combines molecular biology and experimental taphonomy to investigate how microbial energy metabolisms under aerobic and anaerobic conditions influence fish tissue decay and early-stage mineralization. Water chemistry and decay-associated mineral phases were also characterized to assess how microbial processes modify microenvironmental conditions relevant to early fossilization.

Predicted functional profiles revealed that the microbiomes in aerobic decay were enriched in genes associated with fatty acid catabolism, oxidative phosphorylation, and the tricarboxylic acid cycle, indicative of near-complete oxidation of organic matter. In contrast, the anaerobic microbiomes were enriched in genes for butyrate and acetogenic fermentation and anaerobic respiration, consistent with incomplete organic matter degradation. These findings demonstrate that anaerobic settings not only limit scavenger activity but also foster microbial communities whose metabolisms leave greater quantities of residual organic matter, thereby increasing the window for mineralization and biomolecule preservation. X-ray diffraction (XRD) and scanning electron microscopy coupled with energy-dispersive spectroscopy (SEM–EDS) revealed that, irrespective of aerobic or anaerobic conditions, magnesium phosphates and sodium sulfates were the primary minerals formed during fish decay, suggesting these phases represent precursor mineralization products capable of diagenetic transformation into more stable phases.

[1] Elson, A., et al., Fossilisation of Fish Soft Tissue in Oxidative Microniches of Anoxic Sediments. Environmental Microbiology. 27. 10.1111/1462-2920.70188.

[2] Dhami, N.K., et al., Microbially mediated fossil concretions and their characterisation by the latest methodologies: a review. Frontiers in Microbiology, 2023. 14: p.