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Biogeochemical alignments: the coupling of ecology and geochemistry in the deep biosphere

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Explorations of the key biogeochemical process that sustain life on earth are now supported by biomolecular and geochemical analyses that provide highly-resolved data on the spatiotemporal distributions of (i) elements, (ii) organisms across the tree of life and (iii) the extant and fossil cell membrane components that separate cells from their abiotic environment. With the goal to evaluate the coupling among physical, geochemical, and ecological signals in marine sediments, and thus the factors that select for vast, benthic microbial populations, the role of benthic microbes in the C cycle, and the fundamental properties of life at extreme energy limitation, we acquired a comprehensive set of sedimentological and geochemical parameters, reads of the V6 region of bacterial and archaeal 16S rRNA genes, and concentrations of 786 distinct microbial lipids belonging to nine lipid classes. Multivariate statistical approaches based on ordinations and Procrustes analysis were used to align these three components by examining geochemical parameters, microbial marker genes, and lipids from 48 sampling sites, covering a diverse array of depositional regimes, geochemical zones, and sediment age, including the eastern and western Mediterranean basins, the Marmara and Black Seas, and the Rhône River Delta. The resulting Procrustes comparisons were evaluated both in terms of significance (p-value) and against a benchmark value representing the uniform and acknowledged Redfieldian coupling of plankton and nutrients in seawater, expressed as a Procrustes dissimilarity measure rather than the well-known ratio: 106C:16N:1P. In doing so, we have begun to characterize the strength of interplay between past and present microbial communities and their biogeochemical environment. We found significant coupling of benthic archaeal and bacterial populations only in the Rhône River Delta, a system characterized by high sedimentation rates. Lipid and microbial diversity were best coupled among sulfate-methane transition and methanogenesis zones, where the distributions of ether-linked lipids and quinones were redundant with that of both archaeal and bacterial operational taxonomic units (OTUs). The distribution of branched tetraether lipids were typically best coupled to the 54 measured geochemical variables that defined the sedimentary environment across all depositional regimes, which likely reflect similar terrestrial origins of both minerals and lipid fossils. Finally, based on our analyses, we propose a preliminary metric to evaluate the association of ecological and geochemical processes across a wide array of environmental systems, allowing one to compare the coupling of almost any biogeochemical data to that of the well-established plankton-nutrient relationship described by Redfield.