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What biogeochemical information is preserved in the lipids of extreme Archaea?

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All life as we know it builds cell membranes that serve as an essential barrier from the external environment and facilitate the flow of matter and energy. The lipid membrane composition and its isotope composition may record information about the environment where it was synthesized and these signatures can be preserved in sediments over geologically relevant time scales [1,2]. Of particular interest for astrobiology are microorganisms that thrive under extreme conditions. To understand what information can be preserved in the lipids of extremophilic archaea, we seek to construct interpretative frameworks for their lipid composition and isotope signatures in response to environmental conditions.

In this talk, I will demonstrate metabolic and energetic considerations needed to interpret changes in archaeal lipid structures and hydrogen isotope compositions. First, the effect of carbon and energy metabolism on membrane cyclization was tested by cultivating the thermoacidophilic archaeon, *Acidianus* sp. DS80, on different electron donors, electron acceptors, and carbon sources. We found that the patterns of membrane cyclization did not always align with thermodynamic predictions of energy yield; considering the kinetics of cellular energy metabolism provided a more comprehensive explanation for the observed lipid composition [3]. Second, we conducted stable isotope probing experiments with a hyperthermophilic archaeon, *Archaeoglobus fulgidus*, to test the effects of carbon metabolism (autotrophy *vs*. heterotrophy) and physiology on lipid-water isotope fractionation ($\varepsilon_{L/W}$). The effects on archaeal lipid $\varepsilon_{L/W}$ were subtle in comparison to those observed in bacterial lipids [4]. Furthermore, comparison of $\varepsilon_{L/W}$ values from across the three domains of life revealed that the range of archaeal lipid $\varepsilon_{L/W}$ observed across a variety of species and growth conditions (from extreme to neutral pH and temperature) is significantly narrower than that of the bacterial counterpart [4]. These findings inform our interpretation of archaeal lipid distributions and isotope signatures in extreme environments, which provide useful insights for terrestrial analog studies in astrobiology and potential applications on extraterrestrial rocky bodies.

[1] Brocks and Pearson (2005), *Rev. Mineral. Geochem.* 59:233-258. [2] Sessions *et al*. (2004), *Geochim. Cosmochim. Acta* 86:1545-1559. [3] Rhim, Zhou *et al*. (2024), *Appl. Environ. Microbiol.* 90:e01369-23. [4] Rhim *et al*. (2023), *bioRxiv* 2023.11.29.569324.