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Chemosynthetic Life Beyond Hydrothermal Vents: Exploring the Lipidome of the Serpentinite Biosphere

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Serpentinization, the alteration of ultramafic rocks by water, is accompanied by the release of molecular hydrogen (H_2), generating enough redox potential to reduce of CO_2 to methane (CH_4) and to sustain hydrogenotrophic and methanotrophic microbial communities. Whereas serpentinization ecosystems associated with hydrothermal vents have received considerable attention, serpentinization also sustains ecosystems in subduction zones, transform faults, and other deep-seated ultramafic rock settings. The Mariana forearc, where slab-derived aqueous fluids infiltrate the mantle wedge, hosts one such extreme biosphere. This serpentinite mud volcano environment is shaped by highly alkaline fluids rich in H_2, CH_4, and dissolved inorganic carbon. Episodic delivery of metabolic substrates sustains microbial life, though its abundance is limited, presumably by high pH and low nutrient availability. Our lipid biomarker data from serpentinite mud with alkaline porewater reflect a shift from early methanogenesis to sulfate-dependent anaerobic oxidation of methane (AOM). This transition distinguishes the Mariana forearc as a unique endmember among serpentinite-hosted biospheres, marked by prevalent methanotrophy and isotopically depleted $\delta^{13}C$ compositions for methanogen-related biomarkers. A broader perspective on rock-hosted chemosynthetic life emerges when comparing these findings with lipid signatures of serpentinized peridotites from the Romanche Transform Fault, Mid-Atlantic Ridge. These rocks exhibit a high abundance of ether-based archaeal and bacterial glycolipids, similar to those detected at the Mariana forearc. These lipid signatures are indicative of chemosynthetic life in an iron-rich, H_2-generating environment, which is in contrast to the present-day situation where the rocks are exposed to oxygenated seawater. We interpret our finding as fossilized microbial communities that inhabited the rocks before they were exhumed, suggesting that this deep rock-hosted habitat may have sustained life over geological timescales. Unlike dynamic and productive hydrothermal vent ecosystems, serpentinite-hosted biospheres support slow-growing, often carbon-limited microbial communities that persist in challenging environments (scarce nutrients, high pH). Investigating these systems expands our understanding of chemosynthetic life under extreme conditions, providing crucial insights into early Earth habitats and reinforcing the potential of serpentinization-driven ecosystems as key targets in the search for biosignatures beyond Earth.