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Hydrothermal mixing: Fuel for life in the deep-sea

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Deep-sea hydrothermal vent systems show a wide range of fluid compositions and temperatures. They reach from highly alkaline and reducing, like the Lost City hydrothermal field, to acidic and reducing conditions, (e. g., the Logatchev hydrothermal field) to acidic and oxidizing conditions (e. g., island arc hosted systems). These apparently hostile vent systems are generally accompanied by high microbial activity forming the base of a food-web that often includes higher organisms like mussels, snails, or shrimp.

The primary production is boosted by mixing of chemically reduced hydrothermal vent fluids with ambient seawater, which generates redox disequilibria that serve as energy source for chemolithoautotrophic microbial life. We used geochemical reaction path models to compute the affinities of catabolic (energy-harvesting) and anabolic (biosynthesis) reactions along trajectories of batch mixing between vent fluids and 2 °C seawater. Geochemical data of endmember hydrothermal fluids from 12 different vent fields (Lost City, Rainbow, Logatchev, TAG, EPR 21°N, Manus Basin, Mariana Arc, etc.) were included in this reconnaissance study of the variability in metabolic energetics in global submarine vent systems.

The results show a distinction between ultramafic-hosted and basalt-hosted hydrothermal systems. The highest energy yield for chemolithotrophic catabolism in ultramafic-hosted hydrothermal systems is reached at low temperature and under slightly aerobic to aerobic conditions. The dominant reactions, for example at Rainbow or Lost City, are the oxidation of H_2, Fe^{2+} and methane. At temperatures $>60\,^{\circ}C$, anaerobic metabolic reactions, e. g., sulphate reduction and methanogenesis, become more profitable. In contrast, basalt-hosted systems, such as TAG and 21°N EPR uniformly indicate H_2S oxidation to be the catabolically dominant reaction over the entire microbial-relevant temperature range.

Affinities were calculated for the formation of individual cellular building blocks from inorganic reactants (H_2, CO_2, NH_4^+, HPO_4^{2-}, etc.), which include amino acids, sugars, amines, nucleic acids, and fatty acids. Again, ultramafic-hosted sites are distinct from their volcanically-hosted counterparts in that biosynthesis reactions are much less energy-demanding. For a range of biosynthesis reactions, including the formation of proteins, vent systems like Lost City have a fairly wide window of temperature (i. e., fluid mixing ratio) in which biosynthesis reactions are actually endergonic. These favourable energetics of anabolism help microorganisms grow rapidly when conditions are favourable. These results also have potential implications for the development of early life, as alkaline and reducing vent fluids generate an environment that appears to lower the energetic demands of biosynthesis reactions considerably.