Thermodynamic analysis of microbial metabolism in hydrothermal systems

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By catalyzing a wide variety of oxidation-reduction reactions, subsurface communities of microorganisms have a significant impact on their geologic environments. To better understand this impact, we have developed a quantitative thermodynamic model describing microbial coupling of irreversible redox reactions to otherwise endergonic biochemical reactions responsible for synthesizing biomass at elevated temperatures and pressures. Because microbes consist of approximately 80% protein and nucleic acids by dry weight, we have focused on quantifying the conversion of environmentally available energy into these biomacromolecules from their constituent monomers, amino acids and nucleotides, respectively.

The flow of electrons in a microbe resulting from any type of catabolic strategy is, through a complicated set of reactions, coupled to the synthesis of ATP, the universal energy currency of all cells. Organisms in turn couple the Gibbs free energy-liberating hydrolysis of ATP and other nucleotide triphosphates to the energy-demanding dehydration reactions required to polymerize proteins and nucleic acids. Hence, quantitative description of the synthesis of ATP by way of electron flow and the biosynthetic demand-driven hydrolysis of ATP is crucial to understanding the energetics of microbial growth. The microbial coupling model developed in the present study can be used to quantify the polymerization of proteins and nucleic acids in terms of the flow of electrons from any donor to any acceptor and the subsequent synthesis of ATP from ADP. We present the results of calculations that can be used to determine the production of microbial biomass generated in terms of nucleic acids and proteins in a variety of environments characterized by differing temperatures, pressures, and bulk compositions.

Energetic constraints on subsurface biomass production within the igneous ocean crust

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Deep-sea hydrothermal vents have long been recognized to host prolific biologic communities that rely on chemical energy as their source of primary biomass production. More recently, it is becoming increasingly apparent that the high-temperature vents may just be the tip of the biological iceberg, and that there may be substantial biomass living below the subsurface along mid-ocean ridges and within the basaltic crust. Owing to the scarcity of organic material in seawater and basaltic rocks, any sustantial biologic communities living within the subsurface must also rely primarily on chemical sources of energy.

Subseafloor environments are just in the early days of exploration. Consequently, little is yet known about what organisms live there, how many there are, where they live, or what their metabolic activities are. However, because these communities are likely to be largely dependent on chemical sources of energy, we can gain some insight into the likely abundance, spatial distribution, and metabolic activities of subsurface microbial populations by examining the sources of chemical energy that are available to support the community.

I will present results of an energetic evaluation of several different seafloor habitats that owe their existence to ongoing hydrothermal and geologic processes along mid-ocean ridges, including diffuse subsurface mixing zones, weathering of rocks on the seafloor, downflow zones, and low-temperature alteration of basalt. Diffuse mixing zones, where high-temperature hydrothermal fluids mix with seawater in the subsurface on the flanks of hydrothermal vents, are likley to be the most productive subsurface habitats, with sufficient energy to support biological production much larger than occurs at the well-studied hydrothermal chimneys. Oxidation of rocks at the seafloor and in downflow zones also has the potential to support substantial populations of microbes. In contrast, there is relatively little energy available to hydrogen-based methanogenic communities like those that have been proposed to exist in terrestrial basalt aquifers, suggesting this type of environment makes relatively little contribution to total subsurface microbial carbon fixation. Altogether, there is sufficient energy in seafloor environments to support about 10^{12} g (dry wt) of primary biomass production per year.