Minimum Energy Requirements of Methanogenic Microbes

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Any extant extraterrestrial life in the solar system must be confined to subsurface environments, and therefore limited to chemotrophic and likely anaerobic metabolism. Under these circumstances, the ability of geochemical energy release to meet minimum biological energy requirements is a significant factor affecting the distribution and activities of life. To better understand this potential energetic boundary condition, we quantified the minimum free energy requirements for methanogenic microbes in aquatic sediments, which provide an analog for the dark, anoxic conditions of subsurface habitats. Using measured concentrations of H_2, CO_2, methane, and H^+, we calculated the free energy yield of methanogenesis versus depth in cores of brackish sediment. Methanogenesis did not occur significantly in the upper 16 cm of sediment due to the presence of sulfate. Efficient utilization by sulfate reducers held H_2 concentrations at levels corresponding to methanogenic energy yields of -1.4 to -6.4 kJ/(mol CH_4). Although these energy yields make the reaction thermodynamically favorable, they appear insufficient to support metabolism. Methanogenesis occurred actively in the underlying sulfate-free zone, with energy yields as small as -13 kJ/(mol CH_4). Thus, minimum free energy requirements for methanogens in this system appear to lie between -6.4 and -13 kJ/(mol CH_4). The calculated energy yields for active methanogenic metabolism are about half the -20 kJ/mol previously thought necessary for active growth and are squarely within the range observed in other natural systems. Smaller energy requirements imply that a greater fraction of planetary subsurface environments may be "energetically habitable" than would otherwise be thought.