Hydrogen syntrophy-driven methanogenesis by hyperthermophiles in hot subsurface environments

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Nearly all the annual global flux of CH_4 to the atmosphere comes from H_2 syntrophy. However, little is known about (hyper)thermophilic CH_4 production in high-temperature subsurface environments such as hydrothermal vents, oil and gas reservoirs, marine sediments, and terrestrial shale beds, which can be anoxic, organic-rich, and salty. H_2 syntrophy between hyperthermophilic, H_2-producing heterotrophs (e.g. Thermococcus) and H_2-consuming methanogens (e.g. Methanothermococcus) found in these environments could be a common mechanism for CH_4 production. H_2 was the primary limiting factor for the growth of methanogens in Axial Volcano diffuse vent fluid microcosms incubated at 55°C and 80°C. The addition of tryptone without H_2 to these microcosms demonstrated that methanogenic H_2 syntrophy was possible, involving primarily Thermococcus, Methanocaldococcus, and Methanothermococcus. Thermococcus paralvinellae produced H_2 when grown on a carbohydrate, peptides, or formate without S° present. However, ~ 70 μM H_2 in the background led to growth inhibition, expression of formate hydrogenlyase genes, and formate secretion, with a modeled decrease in energy production due to diminished H^+ translocation on the membrane. Among methanogens, the H_2 half-saturation constant for CH_4 production for Methanocaldococcus jannaschii and Methanothermococcus thermolithotrophicum was 27-37 μM with no growth below 3-9 μM H_2. Syntrophic growth of T. paralvinellae with either M. jannaschii or Methanothermococcus sp. BW11 ameliorated H_2-limited growth in both syntrophic pairs, and stimulated growth and H_2 production in T. paralvinellae. Both field and laboratory evidence demonstrate that (hyper)thermophiles cooperate with each other during periods of metabolic stress.