Carbon and energy first: Hydrothermal vents and the origin of microbial metabolism

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Life is a chemical reaction. All cells require carbon, energy, and electrons for growth. One very ancient pathway serves all three needs simultaneously. In the acetyl-CoA pathway, H_2 reduces CO_2 to pyruvate for carbon supply, while methane (archaea) or acetate (bacteria) synthesis are coupled to ion pumping and energy conservation via the rotor-stator ATP synthase. Simplicity and thermodynamics implicate the acetyl-CoA pathway as the most ancient route of carbon assimilation. Fe, Co, and Ni in the active sites of its enzymes are relics of origins. Using Fe^0 or Ni^0 as catalysts, aqueous H_2 and CO_2 react specifically to formate, acetate, methane, methanol, and pyruvate overnight at 100 °C in the laboratory. Solid state Ni^0 alone can replace the function of 140 enzymes required to convert H_2 and CO_2 to pyruvate and methane in cells, Ni^0 can also catalyze reductive aminations of 2-oxoacids, while Fe^0 reduces the 4Fe4S clusters of ferredoxin—an evolutionary precursor of flavin-based electron bifurcation. The alkaline conditions (pH 8-11) of serpentinizing (H_2-producing) hydrothermal systems generate very reducing conditions (E_0' up to –900 mV), depositing Fe^0, Co^0, and Ni^0 as metals. These are precisely the metals that i) reduce CO_2 with H_2 in the laboratory and ii) are present at the active sites of enzymes in the acetyl-CoA pathway. Organic synthesis from H_2 and CO_2 on solid state metals unites hydrothermal environments, ancient microbial metabolism, and inorganic catalysts, converging on the origin of metabolism.