Bibliographic review

The origin of life

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INTRODUCTION

What is life and what we know about it? → Life emerged between the formation of the Earth (4500 million yrs. ago) and the appearance of the first fossils (3400 million yrs. ago). All living organisms have the same genetic code and common metabolic pathways that derive from **LUCA (Last Universal Common Ancestor).** → **"Life on Earth is a self-sufficient chemical system capable of Darwinian evolution"**

But how and where did life emerge? → **Chemical evolution theory** → Early earth conditions allowed the formation of simple organic molecules from inorganic elements, and then more complex molecules such as RNA, peptides and lipids, which led to origin of metabolism and then to life. → The most promising environment currently known for the emergence of life is at the seafloor **Alkaline hydrothermal vents.**

OBJECTIVES

Define which theory of the origin of life is the most widely accepted today.

Explain the theory of the origin of life in the Alkaline hydrothermal vents.

Explain the sequence of events necessary to produce biological systems capable of being self-sufficient and subject to Darwinian evolution.

METHODOLOGY

The work was divided into three stages, the first one consisted of familiarizing myself with the subject through scientific dissemination. The second stage was based on searching and then reading articles and scientific reviews about all the existing theories of the origin of life. In the third stage, I searched and read articles and scientific reviews mainly about the origin of life in the Alkaline hydrothermal vents, and the world of ribonucleoproteins.

RESULTS

The **Alkaline hydrothermal vents** are produced from serpentinization.

Chemical reaction between the ocean water that penetrates 5-7 km deep and the ultramafic rocks (very abundant 4 billion years ago).

Exothermic reaction that **releases H_2 and OH^- ions**, makes the **fluids strongly alkaline** (pH 9-11) and **highly reducing**.

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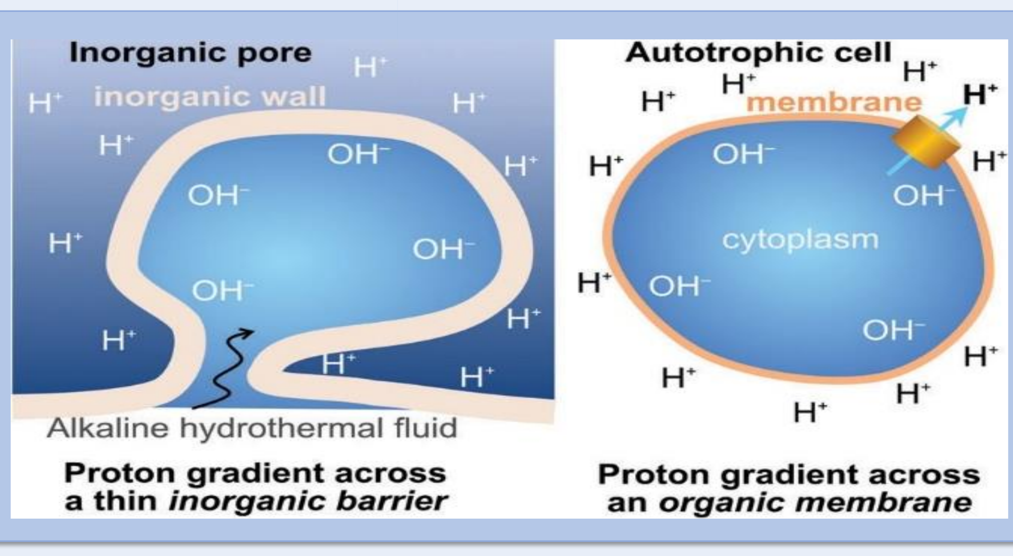
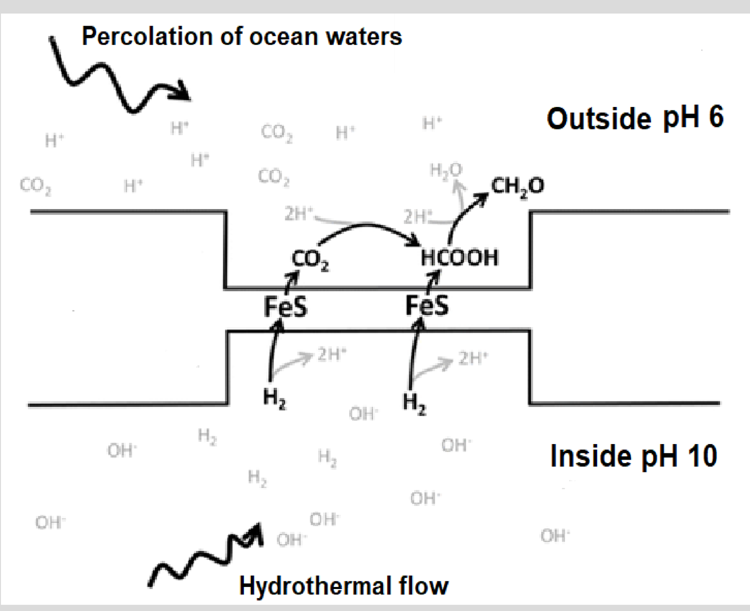
Fluids as they ascend due to their high temperature (70 - 90°C) → drag different minerals and metals from the mantle.
After ascending → **they precipitate** when enter in contact with cold water (1–5°C), **creating rocky column-shaped structures** up to 60 m high, composed of microporous labyrinths inside, of a few micrometers in size.

Hot and cold fluids mix within the micropores, **producing steep gradients of heat, pH, and reduction potential** across thin inorganic barriers.

A **pH gradient of up to 3 units apart** and a difference in potential of around 200 mV is produced → generating a **vectorial chemistry** (like the gradient that exists in **modern autotrophic cells** in terms of **magnitude and polarity**).





In the **Hadean**, the **oceans** were **anoxic and ferruginous** and **slightly acidic**. The abundance of transition metals, such as Fe^{2+} and Ni^{2+} → resulted in the **precipitation of Fe(Ni)S minerals such as mackinawite and greigite** in the pores, partially closing the pore entrance.

Thin minerals walls that have formed at the pore opening, are semiconducting and drive the **reduction of CO_2 to formate (HCOOH)** by electron transfer from H_2 molecules (from the hydrothermal flow) to CO_2 in the acidic ocean water.

Fe(Ni)S minerals catalyze redox reactions → In modern life, inorganic Fe(Ni)S clusters with greigite-like structures (Fe_3S_4) act as **indispensable cofactors** for many enzymes required for carbon fixation and energy transduction.

This suggests that **modern membrane proteins** involved in carbon fixation may have **evolved from these mineral structures.**

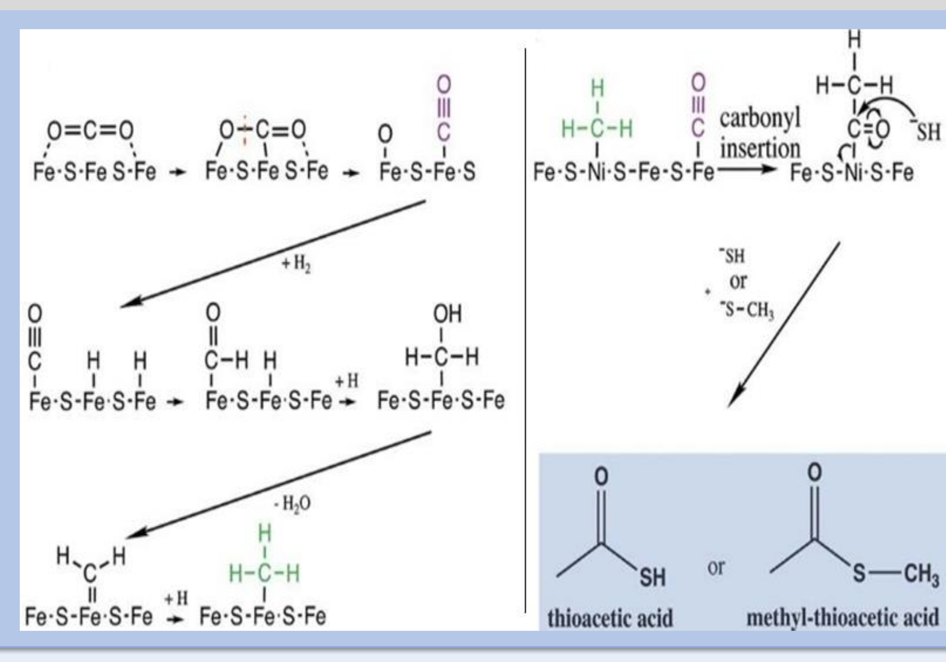
The Wood-Ljungdahl acetyl-CoA pathway → metabolic **carbon fixation pathway** used by some archaea and bacteria is **strikingly similar to the CO_2 reduction in Alkaline hydrothermal vents**.

Wood Ljungdahl acetyl-CoA pathway → is believed to be **the oldest** of the six known carbon fixation pathways in life.

(CODH/ACS) → **key enzyme** of the pathway → has three Fe_4S_4 groups (two of which form a bridge across the sulfide to nickel) → **can be traced back to LUCA.**

Similar abiotic reactions to Wood Ljungdahl pathway possibly happened on Fe(Ni)S mineral surfaces, through Fischer Tropsch-type hydrogenations and Koch-type carbonyl transfers → synthesizing mainly thioacetic acid and methylthioacetic acid.

Thioesters can **improve the catalytic properties of Fe(Ni)S** minerals by **mimicking the active site** of an enzyme and increasing the catalytic surface area, which would accelerate CO_2 reduction.

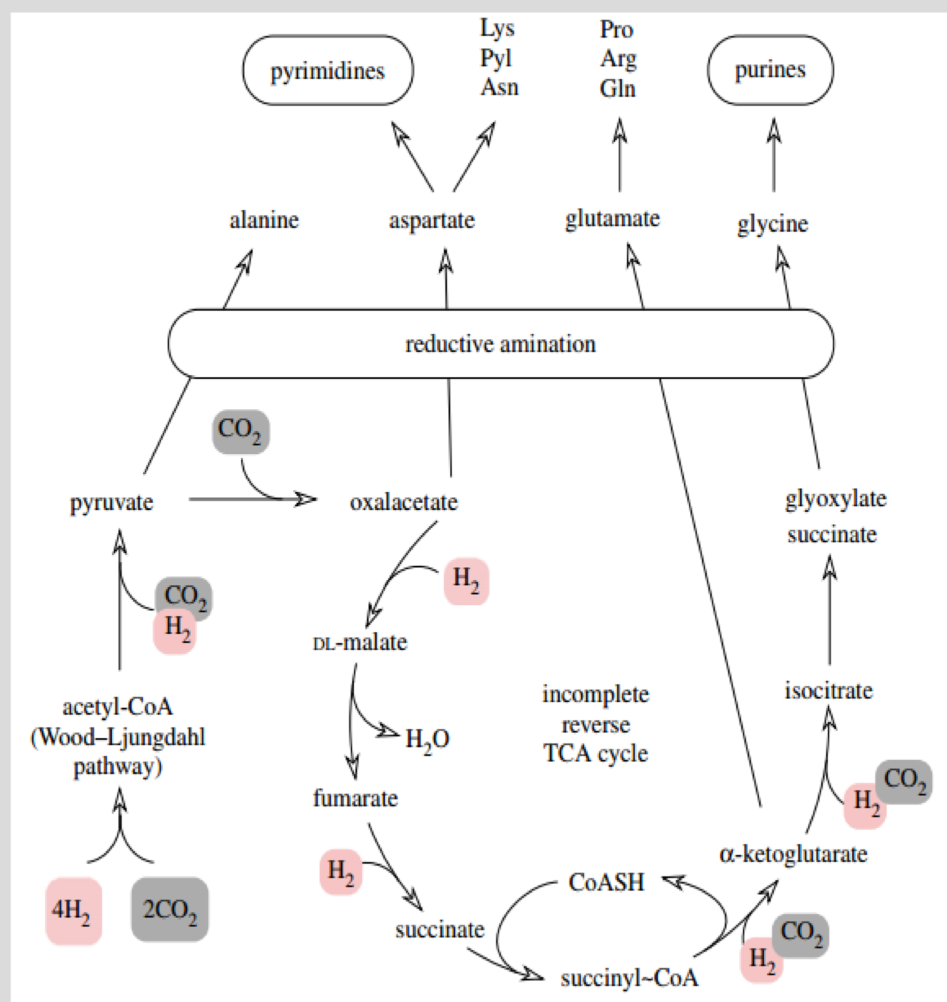


Currently under investigation:
The probability that the precursor of the acetyl CoA (Wood-Ljungdahl) pathway could feed into the reverse incomplete Krebs cycle.

It is known that:
Fe-S mineral surfaces catalyze the synthesis of pyruvate from thioacetic acid.

Hypothetical chemical reactions:
Considering the conditions on a Fe(Ni)S mineral surface → it seems very likely that pyruvate reacts with the mineral surface leading to the **incomplete reverse Krebs cycle**.

Some products of **incomplete reverse Krebs cycle** after amination could lead to the production of **amino acids and nucleotides.**



Synthesis and polymerization of amino acids → It has been concluded that Alkaline hydrothermal vents have energetically favorable conditions.

Experimentally it was observed that oligopeptides were synthesized from glycine.

Experimentally simulated alkaline vent conditions → showed that Fe-S-S-Si mineral precipitates formed on walls could have served as reactors to drive nucleotide oligomerization.

Theory of chemical symbiosis → Biological systems were initially established through collaboration between peptides and nucleic acids, causing the emergence of **ribonucleoproteins**

- **Ribosomes** are evidence of the ancient symbiosis between nucleic acids and amino acids.
- The symbiosis between nucleic acids and amino acids provides **stability** and **catalytic versatility**.
- **It is unlikely** → the existence of an RNA-only world due to its limited catalytic capacity, or of a peptide-only world due to its inability to store genetic information,

Origin of membranes → lipid synthesis and bilayer vesicle formation under alkaline hydrothermal conditions is possible → lipid membranes isolated the chemical systems, creating the first "individuals" subjected to Darwinian selection.

Escape from the Alkaline hydrothermal vents → when life acquired the capacity to create their own proton gradients through their lipid membranes, pumping protons actively

CONCLUSIONS

Conditions in the Hadean's alkaline hydrothermal vents were ideal for the onset of life.

- **The thermodynamic disequilibrium produced by the serpentinization reaction, in addition with the Fe(Ni)S mineral structures formed, such as mackinawite and greigite, favored the origin of protometabolism, laying the foundations of modern metabolism and allowing the synthesis of complex organic molecules from simple inorganic molecules. The formation of amino acids and nucleotides, triggered a symbiosis that would lead to a race for optimization in catalytic processes mediated by mineral structures, giving rise to ribonucleoproteins and lipidic membranes.**

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