Goldschmidt 2025 Abstract
https://doi.org/10.7185/gold2025.31704

The role of silica in the setting of Hadean protoworlds

JUAN MANUEL GARCIA-RUIZ[1], CHRISTIAN JENEWEIN[2], BORJA APARICIO[2] AND FERMIN OTALORA[3]

[1]Donostia International Physics Center (DIPC)
[2]Donostia International Physics Center
[3]Instituto Andaluz de Ciencias de la Tierra

The elegant analogical model of early Earth designed by Miller and Urey [1] demonstrated that prebiotic synthesis can be triggered by involving three components: a source of energy, a reducing atmosphere, and an alkaline ocean. However, they overlooked the role of minerals. It has been demonstrated that the experiment works because of the catalytic effect of the walls of the borosilicate reactor in which it is conducted [2]. We will show that, in the presence of silica or silicate mineral surfaces, lightning experiments lead to the synthesis of prebiotic compounds and an organic film composed of hydrogen cyanide polymers, with nano- to micron-sized biomorphic protocells forming through a mechanism of bubbling and water–gas interfacial precipitation [3]. The experiments operate for a wide range of atmospheric mixtures and different pH values. Our results suggest that protocells and the molecular building blocks of life coexisted on the Hadean Earth within a geochemical framework influenced by large-scale serpentinization, i.e., alkaline hydrochemistry and atmospheric mixtures containing nitrogen and methane [4]. This factory of organic compounds could extend to any celestial body with Earth-like geological features [5]. We propose to term these “protoworlds“, referring to locations in our solar system, galaxy, or universe where the inorganic world may follow different evolutionary paths eventually leading to levels of complexity akin to or even surpassing life as we know it. The success of NASA's Osiris-Rex has brought back to Earth pristine samples from the surface of the near-Earth orbit Bennu 101955 asteroid [6-7]. We will discuss the mineral and organic composition of Bennu as an end-member of a methane-rich and alkaline Hadean protoworld existing within the solar system beyond the earth (Figure 2).

[1] Miller (1953), *Science* **117**, 528-529. [2] Criado-Reyes (2021), *Sci. Rep.*, **11**, 21009. [3] Jenewein (2025), *Proc.Natl.Acad.Sci.*, **122** (2), e2413816122. [4] García-Ruiz (2020), *Phys. Life Rev.*, **34**, 62-82. [5] Saladino (2019), *Chemistry* **25**, 3181-3189. [6] McCoy (2025), *Nature* **637**, 1072-1077. [7] Glavin (2025) *Nat. Astron* **9**, 199-210. [8] Getenet (2023) *Chemical Geology*, **616**,121222.

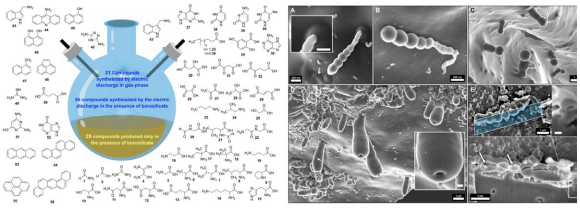
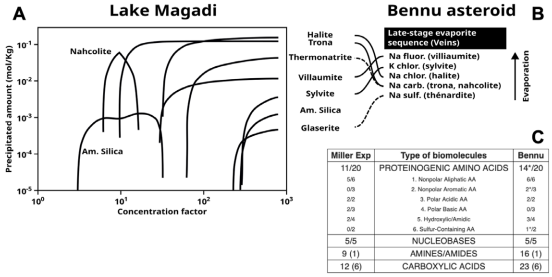


Figure 1: The concomitant synthesis of molecular brick of life and protocells in lighting experiments. (Left) A summary of the molecular diversity found in a Miller-type experiment [2] and a solid poly-HCN film. (Right) Examples of protocells hanging from the organic poly-HCN film overlying the prebiotic soup.



Miller Exp	Type of biomolecules	Bennu
11/20	PROTEINOGENIC AMINO ACIDS	14*/20
5/8	1. Nonpolar Aliphatic AA	6/8
0/3	2. Nonpolar Aromatic AA	2*/3
2/2	3. Polar Acidic AA	2/2
2/3	4. Polar Basic AA	0/3
2/4	5. Hydroxylic/Amidic	3/4
0/2	6. Sulfur-Containing AA	1*/2
5/5	NUCLEOBASES	5/5
9 (1)	AMINES/AMIDES	16 (1)
12 (6)	CARBOXYLIC ACIDS	23 (6)

Figure 2. (A) Evaporitic precipitation sequences for the current waters in alkaline lake Magadi [8] as compared to ((B) the late-stage evaporites of the asteroid (101955) Bennu [6]. (C) Comparison between the organic compounds synthetized in lightning experiments and organic matter found in the asteroid (101955) Bennu [7].