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What do we need for prebiotic chemistry?

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Abstract

Since the Miller Urey experiment, the prebiotic chemistry has been mainly focused on the search of organic matter formation (e.g. amino acids, nucleic bases) that can take a part in the emergence of living organisms. However, fewer researches have been performed on the specific processes that have to develop for obtaining an evolution of these organic matter toward living organisms. In this contribution, by taking the example of amino acids, we will try to understand what could be these processes and in which conditions they could emerge.

1. The origin of organic matter

Understanding the chemical evolution of the organic matter in astrophysical environments gives us clues on the chemical composition of the organic matter that may have seeded primitive planets, and further on the origin of biochemical systems on Earth (Figure 1). The organic matter present in dense molecular clouds in the form of ice mantles at the surface of interstellar grains can evolve toward a complete planetary system. All along this evolution, new and more complex molecules are formed thanks to various energetic processes including UV irradiation and thermal effects. Small bodies of planetary systems (asteroids and comets) eventually serve as a reservoir of this organic matter and as vectors for its delivery at the surface of telluric planets such as the primitive Earth. Therefore, there is probably a link between the molecules contained in cometary or meteoritic grains, and the molecules present in interstellar grains of the primitive dense molecular cloud.

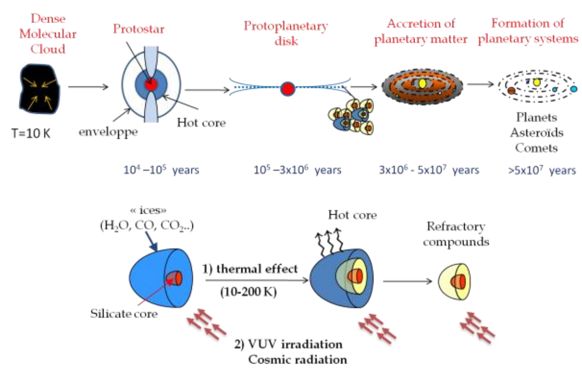

Figure 1- Evolution of the interstellar matter from the dense molecular cloud to its repartition inside planetary systems in a low-mass star system.

2. The case of amino acids

By taking the example of amino acids and particularly of glycine, we will follow the evolution of this organic matter from dense molecular clouds to planetary systems. Based on laboratory experimental simulations and analyses of astrophysical objects such as meteorites, we will try to understand in which environments these molecules can be formed and found. We will demonstrate that these amino acids can be directly formed from carbamate species [1] at the surface of interstellar grains, from specific precursors in various astrophysical environments through the Strecker synthesis [23] or from the hydrolysis of compounds with high molecular mass [4]. We will then try to define the impact that they could have on the emergence of life at the surface of telluric planets. Since these amino acids can be formed in various astrophysical environments, they may be available as a source of organic matter for the development of life at the surface of telluric planets.

3. Organic matter is needed but not sufficient

However, this source of amino acids is it sufficient for the development of living systems? The emergence of biochemical systems can be understood as resulting from the development of more complex chemistry under the chemical and physical conditions of the environment. This transition requires the emergence of molecular entities or reaction networks able to reproduce themselves and then to take advantage of the specific kind of stability associated with things that can be replicated [5]. The organic matter alone cannot be sufficient for a such development. This kind of prebiotic chemistry could only develop in specific environments, where physical and chemical conditions can maintain a dynamic chemical networks in a far from equilibrium state by constantly feeding the system with matter and energy. The association of this matter with energy provide the development of such systems. Consequently, the use of the term "prebiotic", with the meaning “closely preceding the emergence of life” to qualify these environments, should be restricted to the ones in which free energy with a high potential is present. It should not be applied to astrochemistry as a whole, unless a sufficient amount of energy is available. Amino acids found in astrophysical environments can be considered as prebiotic only in environments that are prebiotics.

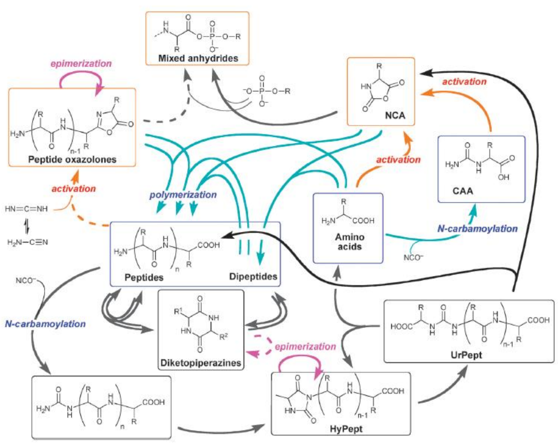

Figure 2: Example of a prebiotic chemical network that associates organic matter, e.g. amino acids, and energy for providing the formation of peptides in a prebiotic environment, meaning the primitive Earth.

An example of a chemical system [6] allowing the formation of peptides from a pool of amino acids in an environment providing a sufficient amount of energy will be presented (Figure 2). For obtaining the formation of peptides, amino acids have to be activated through various pathways allowing the formation of these peptides. This activation is obtained by coupling matter, e.g. amino acids, with physical or chemical energy. If the system is always fed by a constant flow of energy and matter, the initial pool of amino acids can evolve and lead to the formation of more complex structure in term of molecules or chemical networks. This behavior could be the first step toward the emergence of living organisms.

4. Conclusion

Organic matter is found everywhere in the universe, in astrophysical environments (e.g. comets, asteroids) as well as at the surface of planets. However, the organic matter alone is not sufficient for obtaining a chemical evolution toward the emergence of a biochemistry. A such evolution can develop only in specific environments where this matter can be associated with a constant flow of energy. This association can then lead to the development of specific chemical systems able to replicate in a far from equilibrium state.

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