IMPACTS AND THE ORIGIN OF LIFE. A. Brack, Honorary director of research, Centre de biophysique moléculaire, CNRS, Orléans, France. E-mail : andre.brack@cnrs-orleans.fr

Résumé: Les impacts météoritiques marquèrent profondément l'histoire de la vie terrestre. Les gros impacts eurent un effet délétère tandis que météorites et micrométéorites fournirent des molécules organiques indispensables à la vie, par apport direct, mais également indirectement en déclenchant des réactions chimiques. La vie elle-même a peut-être été apportée sur Terre par ces messagers spatiaux selon les partisans de la panspermie.

Introduction: The Earth experienced a large spectrum of impactors ranging from the huge Mars-sized impactor which created the Moon to cosmic dust less than 1 µm in size. Collisions had two antagonistic effects on the history of life. On the one hand, large impacts were deleterious to primitive life in terms of direct extinction and destruction of environments in which life could have appeared or, at least, by significant evaporation of water reservoirs. On the other hand, the presence of carbonaceous components in meteorites and micrometeorites strongly suggests that a large fraction of organic matter on the primitive Earth was of extraterrestrial origin.

The discovery of a large number of meteorites since 1969 has provided new opportunities to search for organic compounds in carbonaceous chondrites [1], [2], [3]. The total number of detected meteoritic amino acid types is now about one hundred. Eight protein-building amino acids have been found. Even biological homochirality could have an extraterrestrial origin since large enantiomeric excesses up to 60% have been found for amino acids in primitive meteorites [4]. Nucleic acid bases, purines and pyrimidines, have also been found in the Murchison meteorite [5]. Ribose was recently identified in the soluble organic matter of carbonaceous chondrites [6]. Vesicle-forming fatty acids have been extracted from different carbonaceous meteorites [7], [8].

Interplanetary dust particle collections in Antarctic ice sheets [9], [10] show that the Earth captures interplanetary dust as micrometeorites at a rate of about 5200 tons per year. α-Amino isobutyric acid has been identified in Antarctic micrometeorites [11]. These grains also contain a high proportion of metallic sulfides, oxides and clay minerals, a rich variety of inorganic catalysts which could have promoted the reactions of the carbonaceous material which led to the origin of life. Analysis of the dust grains collected by the Cosmic Dust mission supports a cometary origin for the micrometeorites collected in Antarctica.

The life cycle of extraterrestrial amino acids, from their formation to their landing on the Earth in meteorites, has been tested, both in the laboratory and in space. Water, carbon monoxide, carbon dioxide, methanol and ammonia ices, which are representative of the ice mantle surrounding interstellar dust particles, have been irradiated at space-like pressures, with electromagnetic radiation representative of the interstellar medium. After the analytical steps, 16 amino acids, including six protein-building amino acids, were identified [12]. Amino acids have been sent back to space, to assess whether they could survive the space trip. A suite of amino acids, like those detected in the Murchison meteorite, were sent into Earth orbit aboard the unmanned Russian satellite FOTON for two weeks, and on the MIR station for three months. Free amino acids were partially destroyed during exposure to solar rays, particularly ultraviolet radiation, but decomposition was prevented when the amino acids were embedded in a 4–5-µm-thick meteorite powder [13]. Of course, for this pathway to be a viable formation mechanism for life on the Earth, these amino acids would then have to survive a trip back through the Earth's atmosphere aboard a meteorite. Impact experiments have shown that only some of the different classes of amino acids tested are able to survive [14].

Intense bombardment probably caused some interesting chemical reactions related to the origin of life [15]. As for the primitive atmosphere reprocessing, laboratory simulations of impact shocks using a high-energy laser showed that the production of organics is highly dependent on the nature of the carbon source: mixtures containing methane generated organic compounds, but no organics could be obtained with mixtures rich in carbon dioxide [16].

Furukawa and colleagues [17] investigated whether, rather than just transporting amino acids, meteorite impacts could themselves synthesize organic compounds. The group subjected a mixture of solid carbon, iron, nickel, water and nitrogen to high-velocity impacts in a propellant gun. This experiment simulated the chemistry experienced by ordinary chondrites — the most common type of meteorite — when hitting the Earth's early oceans. They recovered several organic molecules after the impact, including complex molecules such as fatty acids and amines. Glycine, the simplest protein-building amino acid, was formed when the starting material contained ammonia, which is believed to have been formed in prior impacts on the early Earth. More recently, amino acids have been obtained by laboratory impact-induced reactions among simple inorganic mixtures: Fe, Ni, Mg_2SiO_4, H_2O, CO_2, and N_2, by coupling the reduction of CO_2, N_2, and H_2O with the oxidation of metallic Fe and Ni [18].

One-pot impact-plasma-initiated synthesis of all the RNA canonical nucleobases and the simplest amino acid glycine is possible in reducing planetary atmospheres dominated by carbon monoxide, methane, and molecular nitrogen in the presence of montmorillonite [19]. Shock processed amino acids tend to form complex agglomerate structures [20]. Icy mixtures of amino acids mimicking the icy surface of planetary bodies shocked with high-speed projectiles lead to the synthesis of material architectures that could have played a role in the emergence of life on the Earth [21].

Panspermia, the interplanetary transfer of life, is well documented [22 but has not yet been proved to have any counterpart in reality. Photosynthetic bacteria embedded in the heat shield of unmanned satellite did not survive atmospheric re-entry. This experiment shows that atmospheric entry acts as a strong filter to the interplanetary dispersal of photosynthetic organisms [23].

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