Effect of mechanochemical events into extraterrestrial organic matter and its implications for exogenous delivery

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The RNA World Hypothesis, which states that life began with small RNA-like molecules, is one plausible model for the origin and evolution of life on Earth [1]. With the discovery of ribose, nucleobases, and other molecules of prebiotic interest in meteorite extracts, extraterrestrial delivery has been pointed out as one important prebiotic source of relevant organic molecules [2,3]. It is assumed that most of these molecules were delivered to the surface of the early Earth, which might have contributed to the emergence of life. Though ribose and nucleobases have been found, ribonucleosides and ribonucleotides, the monomers of RNA, have not yet been detected in extraterrestrial samples. The formation of nucleosides from the sugar and nucleobase has not been observed in prebiotic reactions, though other mechanisms of alternative nucleoside and nucleotide formation have been proposed [4]. There has been one detection of a dipeptide in the CM2 Murchison carbonaceous chondrite meteorite [5]. Herein, we evaluate the hypothesis that some of the molecules found in extraterrestrial samples (e.g. nucleobases, sugars, and amino acids) are the remnants (i.e. degradation products) of more complex molecules (e.g. ribonucleosides and peptides). In this context, mechanochemical-induced reactions, resulting from parent body disruptions, micrometeorite/interstellar dust particle collisions, or atmospheric entry, are poorly understood and could contribute to the wide range of extraterrestrial organic matter found on meteorite and asteroid samples.

Solid-state mechanochemical degradation reactions of canonical ribonucleosides (i.e. guanosine, adenosine, cytidine, and uridine) with salts, such as $FeSO_4$, $NiCl_2$, $AlCl_3$, and Na_2CO_3 were experimentally investigated [6,7]. The mechanochemical reactions were performed on a Retsch® MM 400, at 30 Hz, for 90 min and 6 h (cycles of 90 min), in two stainless steel jars (10 mL), with two balls (7 mm) of the same material. Before mechanochemical reaction, some samples were heated in an oil bath (~90 °C) until dryness (3 to 5h) to enable mechanochemical treatment of the sample. Standards of ribonucleosides and salts pre-heated in the same conditions (90 °C) did not show any major signs of degradation. After mechanochemistry, the main degradation product was the corresponding nucleobase (i.e. guanine, adenine, cytosine, and uracil, respectively) [6,7], already detected in meteorite and asteroid samples (e.g. Murchison and Bennu) [2,8]. Other molecules are also produced during experiments but were not fully characterized.
Similar solid-state mechanochemical experiments were conducted using crushed Allende CV3 meteorite powder. Allende was selected since the inorganic chemistry is roughly similar to other carbonaceous chondrites, like Murchison, but has a low abundance of soluble organics and was available for this study. For these experiments the starting mixture contained 1 wt% of ribonucleoside and the mechanochemical reactions were performed at

25 Hz, for 90 min, in similar grinding jars (10 mL) and two balls (7 mm). An additional set of experiments with pure silica and JSC1A (i.e. lunar analogue, also with very low soluble organic abundances) [9] were performed in a Retsch® CryoMill, at 25 Hz for 45 min, in a hardened stainless steel jar (50 mL) with one 20 mm ball of the same material. No preheating was applied to any of these samples. Ribonucleoside degradation was observed in the powdered Allende meteorite, pure silica and JSC1A samples. Further experiments will be performed to explore the reactivity of ribonucleosides through other mechanochemical devices. The influence of organic-mineral interactions on the degradation product will be investigated, with special emphasis to phyllosilicate (major mineral component of matrices of carbonaceous chondrites).

Based on this experimental evidence, it is plausible that mechanical energy can affect soluble organic matter contained in carbonaceous asteroids and meteorites. It may be a viable process for changing the diversity of molecules that were delivered to the surface of habitable worlds.

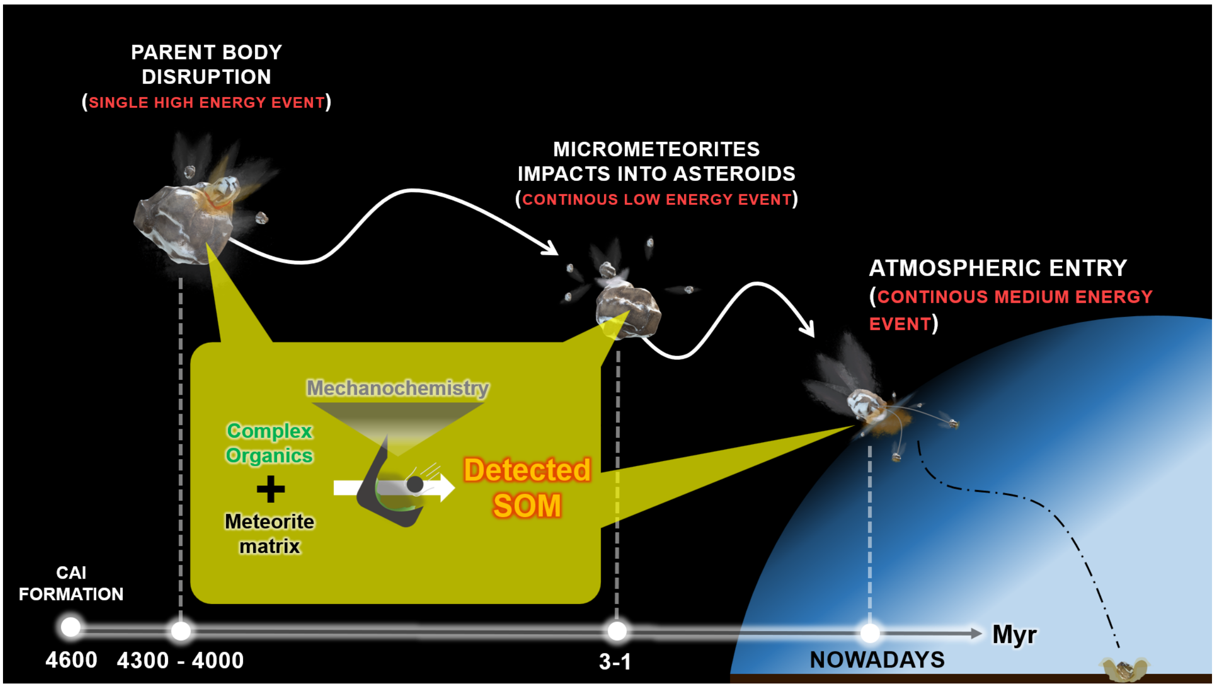

Fig. 1. Mechanochemical events from parent body formation until the present time. Several mechanical-induced events, such as parent body disruption (plausible at ~ 4300 to 4000 Myr ago), space gardening, due to micrometeorite and interplanetary dust particle collisions (~ 3 to 1 Myr ago), and atmospheric entry of meteoroids (present times) could lead to impact/shock transformation into the primordial organic matter, giving rise to some of the organics detected nowadays in meteorite and asteroid samples. This impact/shock chemistry could have changed the diversity of molecules delivered to Early Earth and other habitable worlds. Myr – million years; CAI – Calcium Aluminum Inclusions. This figure is not to scale.

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