THE CATALYTIC ROLE OF CHONDRITIC METEORITES IN THE PREBIOTIC ENRICHMENT OF EARTH AND OTHER PLANETARY WATER-RICH SURFACES, UNDER HIGH METEORITIC FLUX

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Introduction: The carbonaceous chondrites (CCs) are among the most pristine materials arriving to the Earth's surface, and their chemical content reveal that they formed part of undifferentiated parent bodies that kept the primordial components of the protoplanetary disk. The parent bodies of these accretionary aggregates were highly porous and retained significant amounts of water, organics and volatile compounds, available in the outer disk formation regions. Small asteroids and comets are formed by these primordial materials, and at the very beginning were subjected to planetary perturbations and fragmentations during close approaches to planets so probably were easily disrupted [1-2]. At early times we estimated that the early Earth was subjected to a meteoritic flux that could have well been about 5-6 orders of magnitude the current one [3]. It traduces in huge amounts of chondritic materials reaching the Earth's surface at an annual rate of thousands of billions of metric tons [3]. Consequently the amount of volatiles delivered under such high-flux circumstances are also very significant, playing a key role in fertilizing the Earth's surface [4-5]. Then, the reactive minerals forming CCs reached the surface of Earth and other planetary bodies, being exposed to a warm, and water-rich environment that was probably promoting the first steps towards the origin of life [6-7].

To support the previously outlined hypothesis we have recently made a significant progress in understanding the role of chondrites in prebiotic evolution. We analyzed the catalytic effect of six CCs (Table 1) in presence of water and formamide, namely Allan Hills 84028 (group and petrologic type: CV3), Elephant Moraine 92042 (CR2), Miller Range 05024 (CO3), Larkman Nunatak 04318 (CK4), Grosvenor Mountains 95551 (C-ung), and Grosvenor Mountains 95566 (C2-ung). The carbonaceous chondrites (CCs) were requested to the Johnson Space Center facility in the framework of two Spanish research projects (AYA2011-26522 and AYA2015-67175-P) to identify pristine meteorites in the NASA Antarctic collection, and study their properties [7].

Technical procedure: Approximately 50 mg of the stone were ground in an agate mortar. The extraction of the meteorite powder to remove endogenous organics was carried out in two steps as previously reported [6]. Mass spectrometry was performed by the following program: injection temperature 280°C, detector temperature 280°C, gradient 100°C×2min, 10°C/min for 60 min. To identify the structure of the products, two strategies were followed. First, the spectra were compared with commercially available electron mass spectrum libraries such as NIST (Fison, Manchester, UK). Secondly, GC-MS analysis was repeated with standard compounds. The results clearly indicate that carbonaceous chondrites catalyze the synthesis of natural nucleobases, carboxylic acids, and amino acids from mixtures of NH_2CHO and water at 140 °C. Two general scenarios were analyzed: thermal water (TW) and seawater (SW), both tested in the presence of the CCs [7].

Meteorite	Group	Collection
ALH 84028	CV3	Antarctic, NASA
EET 92042	CR2	Antarctic, NASA
GRO 95551	C-ung	Antarctic, NASA
GRO 95566	C2-ung	Antarctic, NASA
LAR 04318	CK4	Antarctic, NASA
MIL 05024	CO3	Antarctic, NASA

Table 1: CCs selected for our study.

Results and discussion: Our experiments presented in [7] confirm that carbonaceous chondrites in presence of warm water and formamide catalyze the synthesis of natural nucleobases, carboxylic acids, and amino acids from mixtures of NH_2CHO and water at 140 °C (see Figure 1). This experimental evidence supports a parent body origin for the complex organic compounds found in CCs, probably coming from hydrated asteroids as previously suggested [8-10]. Secondary minerals being the product of such primordial aqueous alteration were originated in a first stage of water release due to radiogenic heating [8-9], and show evidence of static aqueous alteration with limited water availability producing complex organic chemistry [9-13]. Still in such restrictive conditions the reactive minerals could act as catalyzers and promote increasing organic complexity in chemical evolution, tens of millions of years before to be completed the formation of Earth [7]. These results shape a prebiotic scenario consisting of CCs debris reaching the Earth's surface and acting as catalysts, particularly in a volcanic-like environment.

Conclusions: We have performed a series of laboratory experiments with carbonaceous chondrites that demonstrate that these meteorites can actively and selectively catalyze the formation of biomolecules from formamide in aqueous media. Specific catalytic behaviours are observed, depending on the origin and composition of the chondrites and on the type of water present in the system (activity: thermal > seawater > pure). We report the one-pot synthesis of all the natural nucleobases, of aminoacids and of eight carboxylic acids (forming, from pyruvic acid to citric acid, a continuous series encompassing a large part of the extant Krebs cycle). From these results we envision a general prebiotic scenario consisting of carbonaceous meteorite debris reaching the Earth's surface and acting as catalysts in a volcanic-like environment providing heat, thermal waters and formamide. This scenario also applies to other solar system planetary bodies that experienced rich delivery of carbonaceous materials, formerly: Mars, Europe or Titan.

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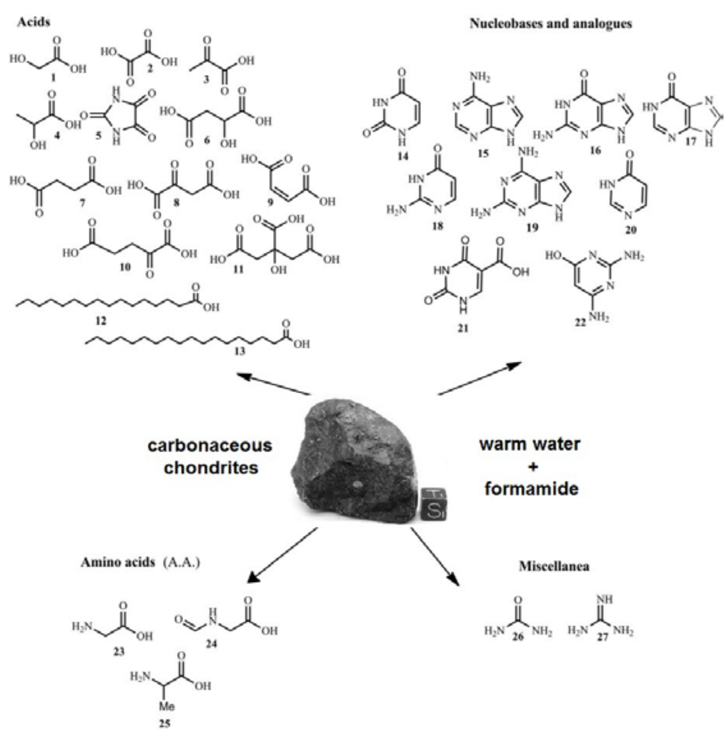

Figure 1. Products of thermal condensation from NH_2CHO/water mixture in the presence of CCs. Experimental conditions: 1% meteorite, 59% NH_2CHO, 40% water, 140 °C, 24 h. A NASA picture of GRO 95551 was chosen as CC generic example in this diagram. For detailed description of the numbered products see Table 1 in [7]