

Carbonaceous Material in Extra-terrestrial Matter

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Abstract. Comets, asteroids, meteorites, micrometeorites, interplanetary dust particles (IDPs), and ultra-carbonaceous Antarctic micrometeorites (UCAMMs) may contain carbonaceous material, which was exogenously delivered to the early Earth. Carbonaceous chondrites have an enormous variety of extra-terrestrial compounds, including all the key compounds important in terrestrial biochemistry. Comets contain several carbon-rich species and, in addition, the hypervelocity impact-shock of a comet can produce several α -amino acids. The analysis of the carbonaceous content of extra-terrestrial matter provides a window into the resources delivered to the early Earth, which may have been used by the first living organisms.

Keywords. meteors, meteoroids

1. Introduction

The inner solar system was bombarded from around 4.5 to 3.8 billion years ago (Schidowski 1988; Schopf 1993; Chyba and Sagan 1992). These impacts may be observed by the impact craters on planetary bodies such as the Moon. Comets, asteroids and their fragments (i.e. meteorite, micrometeorites and interplanetary dust particles (IDPs)) are known to contain carbonaceous material, which was exogenously delivered to the early Earth during that period of time (Anders 1989; Chyba *et al.* 1990; Chyba and Sagan 1992). Interplanetary dust particles (IDPs) can contain up to 50% of organic carbon by mass, but typically have 10% organic carbon by mass (Anders 1989; Schramm *et al.* 1989). Micrometeorites and IDPs are known to contain organic molecules, such as polycyclic aromatic hydrocarbons (PAHs) and alkylated derivatives, aliphatic hydrocarbons, ketones and amino acids (Clemett *et al.* 1993; Matrajt *et al.* 2004, 2005). Furthermore, some aromatic compounds present in IDPs are associated with D/H anomalies (Wopenka 1988), while the long aliphatic chains with little ramifications present in IDPs may have originated at the edges of the protoplanetary disk (Matrajt *et al.* 2013). However, it is not certain whether all these molecules, in particular the amino acids are indeed indigenous or terrestrial contamination (Clemett *et al.* 1993; Brinton *et al.* 1998; Flynn 2003; Matrajt *et al.* 2004). Ultra-carbonaceous Antarctic micrometeorites (UCAMMs) contain up to 90% of carbonaceous material (Duprat *et al.* 2010; Dartois *et al.* 2013). UCAMMs contain unusually high nitrogen- and deuterium-rich organic matter, with bulk atomic N/C ratios of 0.05 and 0.12 (locally exceeding 0.15). They were proposed to be formed in very low temperature regions of the Solar System, such as the surface of small objects beyond the trans-neptunian region (Dartois *et al.* 2013). Carbonaceous meteorites contain up to 5wt% of organic carbon (Alexander *et al.* 2013), which is either locked in an insoluble kerogen-like polymer, or in a rich organic inventory of soluble organic compounds (Cronin and Chang 1993; Cody and Alexander 2005; Martins and Sephton 2009). There are several differences in abundance and distribution of the soluble organic

content between different carbonaceous meteorites. This may result from different physical and chemical processes such as thermal metamorphism (Burton *et al.* 2011; Chan *et al.* 2012), or aqueous alteration on the meteorite parent body (Glavin *et al.* 2006; Martins *et al.* 2015). Comets also have several extra-terrestrial organic molecules (Crovisier and Bockelée-Morvan 1999; Ehrenfreund *et al.* 2002), including the simplest amino acid glycine (Elsila *et al.* 2009). Most recently the results from the Rosetta mission of the surface of comet 67P/Churyumov-Gerasimenko were published. Carbon-rich species, including alcohols, carbonyls, amines, nitriles, amides, isocyanates, and the radiation-induced polymer polyoxymethylene were detected (Goesmann *et al.* 2015; Wright *et al.* 2015). In addition, the impact-shock of comets produces complex organic molecules (Martins *et al.* 2013).

2. Synthesis of amino acids via the impact-shock of comets

Goldman *et al.* (2010) performed ab initio molecular dynamics simulations that showed that shock waves passed into ice mixtures representative of comets, could theoretically yield amino acids. Amino acid precursors (such as ammonia, methanol and carbonyl compounds) have been observed in comets, e.g. Halley, Hyakutake, Tempel 1, Giacobini-Zinner, Hartley 2 and Hale-Bopp (Festou *et al.* 2005; DiSanti *et al.* 2013; Crovisier and Bockelée-Morvan 1999; Ehrenfreund *et al.* 2002; Ehrenfreund and Charnley 2000; Mumma *et al.* 2003; Bockelée-Morvan *et al.* 2000). Therefore, it has been experimentally tested in the laboratory whether the hypervelocity impact-shock of a typical comet ice mixture would synthesize amino acids (Martins *et al.* 2013). Results show that the impacts of comets onto rocky surfaces, and the impacts of meteorites onto icy surfaces (such some of the Jovian and Saturnian satellites) produce several α -amino acids. Several lines of evidence prove that the detected amino acids were indeed synthesized by impact-shock (Martins *et al.* 2013):

- A racemic mixture of alanine was detected, with a D/L ratio of 0.99, and a racemic mixture of norvaline was also detected with a D/L ratio of 0.97;
- Structural diversity and the decrease of amino acid abundances with increasing number of carbon atoms were observed;
- The non-protein amino acids α -aminoisobutyric acid (α -AIB) and isovaline were obtained;
- The synthesis is in agreement with ab initio molecular dynamics simulations modelling (Goldman *et al.* 2010);
- The control ice samples and the extraction procedural blanks were completely free from organic compounds.

The synthetic pathway to create amino acids via impact-shock is not completely clear. Suggested synthetic pathway includes the Strecker-cyanohydrin synthesis using α -amino acid precursors (carbonyl compounds, ammonia, and hydrogen cyanide). In this case, the carbonyl precursors (aldehydes and ketones) would be synthesised by the oxidation of methanol (present in the simulated ice mixture), which would generate the α -amino acid precursor carbonyl compounds. Support for this is indicated by an ice mixture containing only ammonia and carbon dioxide and lacking methanol. Even with an impact velocity of 7.12 km/s, no detectable quantities of amino acids were produced (Martins *et al.* 2013). To note, however that the impact shock occurs on timescales of nanoseconds to milliseconds, which should not be consistent with the Strecker-cyanohydrin synthesis. Alternatively, a high shock pressure (i.e. at 7 km/s the peak shock pressure experienced by the ice mixture is 50 GPa (Martins *et al.* 2013; Goldman *et al.* 2010)) results in the

formation of ions and radicals, which will then be involved in the post-shock reaction to form amino acids.

In summary, the exogenous delivery of carbonaceous material in our Solar System expands the inventory of locations where life could have potentially originated. In fact, the detection by future space missions of an amino acid racemic ratio on the surface of icy Jovian and Saturnian satellites may be the result of impact shock events as well as the contribution from meteorites.

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