COMETS AND THE FORMATION OF BIOCHEMICAL COMPOUNDS ON THE PRIMITIVE EARTH – A REVIEW

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Abstract. Thirty years ago it was suggested that comets impacting on the primitive Earth may have represented a significant source of terrestrial volatiles, including some important precursors for prebiotic synthesis (Oró, 1961, Nature 190: 389). This possibility is strongly supported not only by models of the collisional history of the early Earth, but also by astronomical evidence that suggests that frequent collisions of comet-like bodies from the circumstellar disk around the star β Pictoris are taking place. Although a significant fraction of the complex organic compounds that appear to be present in cometary nuclei were probably destroyed during impact, it is argued that cometary collisions with the primitive Earth represented an important source of both free-energy and volatiles, and may have created transient, gaseous environments in which prebiotic synthesis may have taken place.

1. Introduction

In 1908 the Tunguska event, which may have been caused by the collision of a small comet with the Earth, took place (Kresák, 1978; Brown and Hughes, 1977). That same year Chamberlin and Chamberlin (1908) suggested that collisions of volatile-rich ‘planetesimals’ with the primitive Earth may have provided organic compounds for allegedly plant-like primordial organisms. However, neither the Chamberlins’ paper nor the Tunguska collision seem to have had a major impact on the theoretical treatment of the question of the origin of life at that time. It was not until 1961 that one of us (Oró, 1961) suggested that comets may have played a role in the appearance of terrestrial life. This suggestion followed closely the prebiotic synthesis of adenine, amino acids and other biochemical compounds from HCN (Oró, 1960), and coincided with a growing awareness that the same precursor was present in cometary nuclei. Thus, it was suggested that cometary collisions may have provided the primitive Earth with an important source of volatiles which subsequently may have been the precursors for the non-biological synthesis of biochemical molecules that preceded the first organisms (Oró, 1961).

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In recent years this possibility has received considerable attention from the scientific community due, among other things, to the presence of a large array of organic compounds in the interstellar environment and in cometary spectra (Oró et al., 1991), the development of theoretical models which predict that the Earth was formed in a region of the solar system devoid of volatiles (Cameron, 1988; Wetherill, 1990), and the discovery of $3.5 \times 10^9$ years old microfossils (Awramik et al., 1983; Schopf, 1983; Schopf and Packer, 1987), whose presence implies that life must have appeared during a period in which collisions with minor solar system bodies played a major role in shaping the surface of the terrestrial planets (Sleep et al., 1989; Oberbeck and Fogelman, 1989 a, b; Oró et al., 1990; Marcus and Olsen, 1991).

But have comets actually played a direct or an indirect role in the origins of life? In this paper we will argue that the answer is positive. To do so, we first review the evidence suggesting that cometary collisions actually provided a substantial fraction of the terrestrial volatiles. We then discuss the presence of organic compounds in cometary nuclei, and their possible fate during cometary impacts with the primitive Earth. The possibility that comparable processes are taking place around other stellar systems such as β Pictoris, is also discussed. Our conclusions are presented in the final section.

The Origin of the Earth-Moon System: Where Did the Terrestrial Volatiles Come from?

Although it is generally accepted that the solar system formed $4.6 \times 10^9$ years ago as a result of the condensation of a solar nebula rich in organic molecules (Wetherill, 1990, 1991), it is unlikely that the compounds from which the first organisms were formed were derived directly from interstellar molecules present in the nebula (Lazcano-Araujo and Oró, 1981). Our planet formed in a region of the solar nebula that may have not been particularly rich in volatiles (Wetherill, 1990, 1991). This conclusion is consistent with recent astronomical observations that have shown that protostellar gaseous envelopes are blown away into the interstellar medium in timescales of $10^6-10^7$ years (Hayashi et al., 1985), and is strongly supported by the well-known terrestrial depletion of noble gases relative to solar abundances (Suess and Urey, 1956; Cameron, 1980; Owen et al., 1991). Moreover, recent calculations suggest that the accretion disk at the distance were the Earth formed was too hot to allow the condensation of volatiles that may have been present (Delsemme, 1992). But if the above is true, from where did the current budget of terrestrial volatiles come?

The answer to this question is closely linked to the origin of the Earth-Moon system. As reviewed by Cameron (1988), before the Apollo missions, theories on the origin of the Earth-Moon system could be grouped in three main classes: (a) the capture theory, which assumed that the Moon was formed elsewhere in the solar system, and was later captured by the Earth; (b) the coformation theory, that stated that the Earth and the Moon were formed in a mutual orbit; and (c) the