There have been brief periods since the beginning of the Cambrian some 600 m.y. ago when mass extinctions destroyed a significant fraction of living species. The most widely studied of these events is the catastrophe at the KT boundary that ended the long dominance of the dinosaurs. In addition to mass extinctions there is another profound discontinuity in the history of Earth's biota, the explosion of life at the end of the Precambrian era, an episode that is not explained well at all. For some 3 b.y. before the Cambrian, life had been present on Earth, but only at a low level of activity, an aspect of the biota that is puzzling, especially during the last two-thirds of that period. During the last 2 b.y. before the Cambrian, conditions at the Earth's surface were suitable for a burgeoning of the biota, according to most criteria: The oceans neither boiled nor were frozen solid during this time, and the atmosphere contained sufficient O for the development of animals. The purpose of this paper is that during the Earth's history the O\textsubscript{3} production rate has been the controlling factor for the biota. Specifically, it is suggested that cometary activity during the Precambrian and comet showers during mass extinction events provided a supply of volatile material to the inner solar system that selectively absorbed UV photons capable of photolyzing the O\textsubscript{3} molecule (and thus precluded O\textsubscript{3} production); at the same time the solar flux at near-UV wavelengths arrived at Earth unattenuated, resulting in an extremely harsh environment for the biota at the Earth's surface and at ocean depths down to several tens of meters.

The comets under consideration consisted of volatile material that accumulated in the region of the nebular disk beyond Jupiter's orbit. Then gravitational perturbations by the four giant planets redistributed a portion of these cometary bodies to form the Oort comet cloud at the outer boundary of the solar system [3]. At the same time a much larger number of these bodies were expelled from the solar system, or were disrupted and vaporized by passing in the vicinity of the Sun [4, 5].

In order to estimate the amount of cometary volatile material that is required to have a critical effect on O\textsubscript{3} production in the atmosphere it is assumed that the rate of O photolysis (O\textsubscript{2} + h\textupsilon \rightarrow O + O) required for O\textsubscript{3} production is proportional to the flux of photons in the extreme UV that drive the reaction; further it is assumed that a reduction of the O\textsubscript{3} production rate of \(\frac{1}{4}\) of its present value would result in an environment sufficiently harsh at the Earth's surface to account for the Precambrian biota or mass extinctions. In the present atmosphere the flux of 200-nm photons is reduced to \(\frac{1}{4}\) of its value at the top of the atmosphere by \(-10^{23}\) O\textsubscript{3} molecules per cm\textsuperscript{2}. However, the cometary volatile material would consist of water (H\textsubscript{2}O) and ammonia (NH\textsubscript{3}), molecules with UV absorption cross sections greater than that of O\textsubscript{3} by factors of 10 and 10\textsuperscript{6}, respectively [2]. Thus an average concentration of \(7 \times 10^{4}\) cm\textsuperscript{-3} of H\textsubscript{2}O, or \(7 \times 10^{6}\) cm\textsuperscript{-3} of NH\textsubscript{3}, would be required along the path connecting the Earth and the Sun. If the cometary material is constrained to a disk 0.1 AU thick the total amount of H\textsubscript{2}O would be \(2 \times 10^{31}\) g, or \(10^{30}\) g of NH\textsubscript{3}. Comparing the collision cross sections of the Earth and the disk (a factor of \(5 \times 10^{8}\)), it is concluded that during the same period the mean time of cometary activity would be \(2 \times 10^{6}\) years. Assuming a residence time of one year for vaporized material in the disk (corresponding to an average velocity of 50 km s\textsuperscript{-1} for the outward transport of the vapor), during the 3 \(\times 10^{9}\) years of cometary activity in the Precambrian \(1.2 \times 10^{31}\) g H\textsubscript{2}O, or \(6 \times 10^{29}\) g NH\textsubscript{3}, would have been deposited on Earth.

It is appropriate to consider two aspects of this proposed scenario for the effect of comets on the history of Earth's biota: whether it is possible and what, if any, further conclusions would result. The most direct quantitative comparison involves the total amounts of H\textsubscript{2}O or NH\textsubscript{3} predicted to have been deposited on Earth by cometary activity [6, 7]. The amount of H\textsubscript{2}O alone that would be required exceeds the amount on Earth by more than 2 orders of magnitude, but the amount of NH\textsubscript{3} required is about equal to the mass of Earth's atmosphere. Thus the proposed scenario seems to meet the zeroth order test, especially where NH\textsubscript{3} is concerned. However, it should be noted that the required amount of volatile material could be an overestimate, since the absence of an O\textsubscript{3} atmosphere for perhaps only 1% of the time during the Precambrian could suffice to suppress the development of the biota on the Earth's surface. Another consideration is the fact that solar luminosity was less during the
Precambrian era. Also, the amount of cometary volatile material that has been deposited on Earth may be more than is found at present, since some of the volatile material may have been removed by impact erosion. In addition, the UV absorption cross sections of cometary \( H_2O \) and \( NH_3 \) may be larger than the values measured in the laboratory, since in comets they could be in the form of cluster molecules [8]. Finally, the continuous introduction of \( H_2O \) and \( NH_3 \) at the top of the atmosphere would not only suppress \( O_3 \) production by UV absorption, but the photolyzed products would catalytically destroy \( O_3 \) by the well-known reactions at work in the stratosphere at present [9].

Since suppression of the \( O_3 \) atmosphere by comets in the inner solar system appears to be possible, it is of interest to note that the same mechanism would resolve two other current problems involving the history of Earth and Mars. The likelihood of \( NH_3 \) in the Precambrian atmosphere was suggested [10] in order to provide the necessary greenhouse effect when solar luminosity was less than its present value, and thus reconcile calculated ocean temperatures with the observation that the oceans had not frozen. However, calculation of \( NH_3 \) photoysis [11] indicated a lifetime for \( NH_3 \) in the atmosphere that was significantly less than that which was required. The presence of \( NH_3 \) and \( H_2O \) in the inner solar system according to the scenario presented here could reduce the rate of \( NH_3 \) photolysis in the Earth’s atmosphere to a level that would permit the small amount of \( NH_3 \) that had been suggested [10]. In a similar way the efficient greenhouse nature of \( NH_3 \), in conjunction with its shielding from solar UV radiation by cometary outgassing in the inner solar system, could account for the warmer temperatures on Mars that are needed to explain the fluvial features that have been observed there.

To summarize the main suggestion proposed here: Discontinuities in the history of Earth’s biota can be explained by the single unifying suggestion that low levels of \( O_3 \) production are controlled by cometary activity. Precambrian biological activity is explained along with mass extinctions. Where mass extinctions since the Cambrian are concerned, comet showers from the remnants of the nebular disk lasting for thousands to millions of years provide a model consistent with the paleontological record, which shows biological degradation lasting for similar periods and becoming increasingly destructive with time until the event suddenly ends. Since the model proposed here appears to answer some outstanding questions it should be investigated further.

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