Asteroid Extinction Hypothesis

A distinguishing feature of the asteroid impact hypothesis presented by Alvarez *et al.* (6 June, p. 1095) for the end-of-Cretaceous biotic crisis is that it is based on direct physical evidence: the distribution of iridium in several Cretaceous-Tertiary sedimentary sections. I draw attention to other evidence which suggests that (i) a high Ir concentration may not be uniquely associated with an extraordinary extraterrestrial event and (ii) the impact of a large asteroid in any case is not likely to have had the dire consequences to life on the earth that they propose.

Crucial to their argument for an asteroid impact at the Cretaceous-Tertiary boundary is the interpretation of the Ir concentration in the boundary clays as anomalously high. Background levels of Ir in modern deep-sea sediments are usually on the order of 0.3 part per billion and can be attributed to the influx of meteoritic dust (*1*). However, much higher values can occur, even in Pleistocene sediments. For example, Crocket and Kuo (*2*) reported Ir abundances of 0.11 to 0.71 ppb from nine levels in deep-sea sediment core Eltanin 21-17. The $CaCO_3$ content of the analyzed bulk samples ranged from 83.0 to 94.9 percent, so that if the bulk Ir contents are recalculated as per weight of insoluble residue, as done by Alvarez *et al.*, they would range from 0.83 to 7.6 ppb, with an average of 2.0 ppb in this core. I suggest that the significance of the 9.1-ppb Ir content in the Gubbio boundary clay, on which the asteroid impact hypothesis largely rests, is open to question in light of the comparable concentration range of Ir in deep-sea sediments of Quaternary age (*3*), a time period for which neither a large asteroid impact nor massive extinctions have been suggested.

But why should "abnormally" high Ir contents occur at the level of the Cretaceous-Tertiary boundary in stratigraphic sections worldwide? As Alvarez *et al.* and others point out, the Cretaceous-Tertiary boundary is often associated with a hiatus, an interval of essentially nondeposition or erosion, even in pelagic marine sediments. Under a steady influx of Ir-bearing meteoritic material onto the earth's surface, Ir would be concentrated in sediment either by a reduced input of terrestrially derived sediments or by their preferential removal by bottom current activity. The latter mechanism seems plausible when one considers that the extraterrestrial material in deep-sea sediments typically occurs as spherules from tens of micrometers to several hundred micrometers in size (*4*)—far in excess of particle sizes of clays (< 2 micrometers) such as those at the Cretaceous-Tertiary boundary in the Italian and Danish sections. The relatively larger size combined with a generally higher density of the cosmic spherules would tend to cause segregation of the meteoritic material from clays in the presence of currents, leading to a highly heterogeneous distribution of Ir in sediments. Thus, the factor of 10 difference in Ir concentration between the Fiskeler in the Danish section and the Gubbio boundary clay could be accounted for. Moreover, Alvarez *et al.* acknowledge the variation in thickness of the Fiskeler, from a few centimeters to as much as 35 centimeters locally (*5*), which can be interpreted as due to local sedimentary control by bottom current activity.

Clearly more data on the distribution and abundance of Ir in sediments are needed to establish whether high Ir concentrations are uniquely associated with extraordinary extraterrestrial events, or more generally occur locally, perhaps associated with sedimentary conditions which may not coincide in time with biotic crises. But regardless of the eventual outcome of these researches, it is of interest to reconsider the proposed effects of a large asteroid impact.

Alvarez *et al.* consider the effects of the historic eruption of Krakatoa and extrapolate them by a factor of $\sim 10^3$ to suggest that the amount of material injected into the stratosphere from the impact of a 10-kilometer asteroid would effectively shut out sunlight for several years, suppressing photosynthesis and causing the collapse of most food chains. However, the 1883 eruption of Krakatoa was small in comparison to other volcanic eruptions in the geologic record, whose effects may be more comparable to those suggested for a large asteroid impact.

A well-known example of the remains of a very large volcano is the Toba caldera in Sumatra, which measures approximately 100 by 35 km; by comparison, the caldera of Krakatoa is only a few kilometers in diameter. A tephra layer several centimeters thick and correlated to the Toba eruption can be found in deep-sea sediment cores more than 2500 km distant from the source, whereas no distinguishable deep-sea tephra deposit from Krakatoa has been found in sediment cores as close as 200 km from the vent (*6*).

But it is difficult to compare these eruptions on the basis of the volume of ejecta, which has been calculated in different ways for Toba (*6, 7*) and Krakatoa (*8*). A more consistent way to estimate their relative magnitude is to compare the volumes of the calderas and assume that caldera volume is proportional to amount of ejecta put into the atmosphere. The volume of the Toba caldera is estimated to be 2000 km^3 (*7*), and that of the Krakatoa caldera to be 5 km^3 (*9*). The expected sunlight attenuation for Toba, calculated with the same assumptions and values used by Alvarez *et al.* but with the effect of Toba 400 times that of Krakatoa, comes to $\exp(-12) \simeq 10^{-5}$. This attenuation factor is not nearly as large as the one postulated by Alvarez *et al.* for the asteroid impact. However, it appears to be more than sufficient to suppress photosynthesis and could presumably have led to at least some of the consequences life on the earth suffered at the end of the Cretaceous according to asteroid impact hypothesis. The pertinent point is that the eruption of Toba occurred 75,000 years ago (*10*), a time that has yet to be noted for massive extinctions or other extraordinary effects on life. Moreover, there is little reason to believe that the magnitude of the Toba eruption was exceptional; even larger explosive volcanic eruptions probably occurred over geological time.

The two principal points raised here—the first concerning the uniqueness of the association of high Ir concentrations in sediment with large asteroid impacts and the second regarding the proposed effects of such an asteroid impact on life on the earth—are independent of each other. That an asteroid impact occurred at the time of the Cretaceous-Tertiary boundary may in time be substantiated by further geochemical work and stratigraphic studies. However, the lack of evidence for serious consequences to global life from large volcanic eruptions, which may approach the ejecta volume postulated for a large asteroid impact, suggests that the cause of the massive extinctions is not closely related to a drastic reduction in sunlight alone, and an alternative mechanism should be sought [for example, (*11*)].

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References and Notes

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Alvarez *et al.* have studied the elemental composition of the materials that are known to have lain at the earth's surface at the time of the Cretaceous-Tertiary extinction and have concluded from the high abundance of iridium that an extraterrestrial event was involved, probably the impact of an earth-crossing asteroid. They suggest that the extinction itself was due to a complete cessation of photosynthesis caused by the obliteration of sunlight by a stratospheric dust layer that persisted for a few years.

The case made by Alvarez *et al.* for an asteroidal impact is a compelling one. Their argument that the immediate effect on the biosphere was the cessation of photosynthesis is less strong. The possibility that the extinction was due to collapse of the photosynthetic food chain was suggested by Crutzen and Reid (*1*) and expanded on by Reid *et al.* (*2*) as one of the potential consequences of a nearby supernova explosion. In the cases considered, however, the magnitude of the reduction in sunlight was on the order of 10 percent at most, in contrast to the reduction by a factor of 10^7 (approximately 10 percent of full moonlight) suggested by Alvarez *et al.* Such a scenario would cause a total collapse of photosynthesis; it would also have global climatic consequences that might place an even more severe strain on the biosphere.

The decay of the climate system following the extinction of sunlight was investigated by Hunt (*3*), using a general-circulation model of the atmosphere. His calculations ran for only 50 days after the extinction, at which time the atmosphere still retained weakened jet streams and meridional temperature gradients. After the 2- or 3-year stratospheric residence time for the dust layer, these climatically important features would presumably have essentially disappeared. The scenario suggested by Alvarez *et al.*, however, is not equivalent to extinguishing the sun, since the earth would be blanketed by a hot dust layer capable of producing a powerful greenhouse effect, perhaps analogous to that existing at