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IMPACT AS A GENERAL CAUSE OF EXTINCTION: A FEASIBILITY TEST;

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Large body impact has been implicated as the possible cause of several extinction events. This is entirely plausible if one accepts two propositions: (1) that impacts of large comets and asteroids produce environmental effects severe enough to cause significant species extinctions and (2) that the estimates of comet and asteroid flux for the Phanerozoic, as calculated by Shoemaker and others, are approximately correct.

A reasonable next step is to investigate the possibility that impact could be a significant factor in the broader Phanerozoic extinction record, not limited merely to a few events of mass extinction. This can be explored by monte carlo simulation experiments, given the existing flux estimates and given reasonable predictions of the relationship between bolide diameter and extinction.

Figure 1 shows a consensus estimate of the average impact flux (comets and asteroids) for the Phanerozoic interval (600 myr BP to present), expressed as the expected waiting time (ordinate) betweeen impacts of objects at least as large as the diameter given on the abscissa. From this plot, impacts by objects of 1 km or larger diameter occur every one million years, on average, and impacts by objects 10 km or larger occur every 100 million years, on average.

The curve relating bolide diameter and extinction ("kill curve") is very poorly constrained but some intelligent guesses can be made. We know, for example, that small bolides, 1 km diameter or less, do not produce measurable extinctions of genera -- as evidenced by the lack of extinctions associated with events such as those producing the Steinheim and Ries craters at 14.8 myr BP. Barring threshold effects, extinction should increase gradually as bolide diameter exceeds the 1 km range. Bolides in the range of 10 km diameter have been suggested for major mass extinctions of the K-T type, and these are associated with extinctions of 40-60% of marine genera. Above this level, the fact that life on Earth has never experienced complete extinction suggests that the curve must approach complete extinction asymptotically.

These considerations suggest a sigmoidal kill curve of the general form shown in Figure 2. Several variants of this curve were used in the

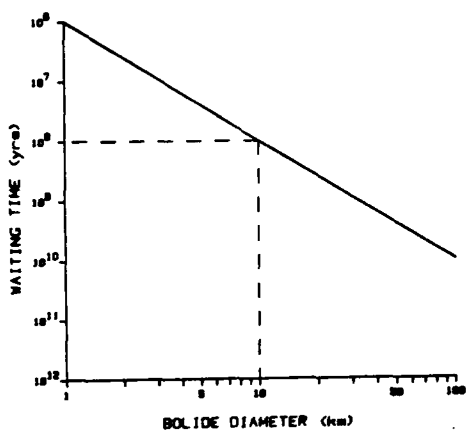

Figure 1. Impact flux.

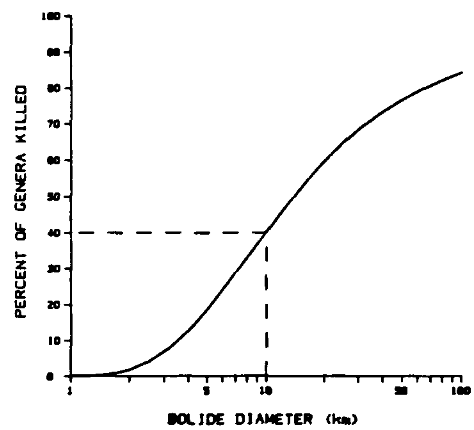

Figure 2. Postulated kill curve.

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simulations reported here. Naturally, the kill curves express only the average expectation: extinction levels should be expected to vary with the nature of the impact, the state of the biosphere at the time of impact, and geographic position of the impact site.

Figure 3 shows the results of one simulation. For each 10,000 year interval in a 600 myr time span, bolide diameter was selected at random using the probability distribution of Figure 1 and this was converted to an extinction intensity using the kill curve of Figure 2. Each event that resulted in extinction (bolide greater than 1 km diameter) is recorded in the plot. [The simulation is based on a pure Poisson process and thus is uncomplicated by additional factors such as periodic extinction or comet showers.]

In order to compare these results with conventional depictions of the Phanerozoic extinction record, it is necessary to group the events into "stratigraphic units." Figure 4 shows the simulated extinction data grouped into standard "stages" of 7.5 myr duration. The result is remarkably similar in structure to the record of generic extinctions developed from Sepkoski's data for fossil marine genera. Repeated simulations using reasonable variants of the kill curve produce comparable results.

The simulation experiments do not "prove" anything about the causes of extinction in the history of life. However, the simulations do raise the serious possibility that large body impact may be a more pervasive factor in extinction than has been assumed heretofore. At the very least, the experiments show that the comet and asteroid flux estimates combined with a reasonable kill curve produces a reasonable extinction record, complete with occasional "mass" extinctions and the irregular, lower intensity extinctions commonly call "background" extinction.

Testing the implications of this study is feasible, although difficult in the present state of knowledge. Testing hinges on the postulated kill curve (Figure 2): if the kill curve used for the simulations is basically accurate, then the structure of the extinction record it produces is inevitable. Only by showing the kill curve to be unrealistic can large body impact be ruled out as a candidate for the general cause of extinction.

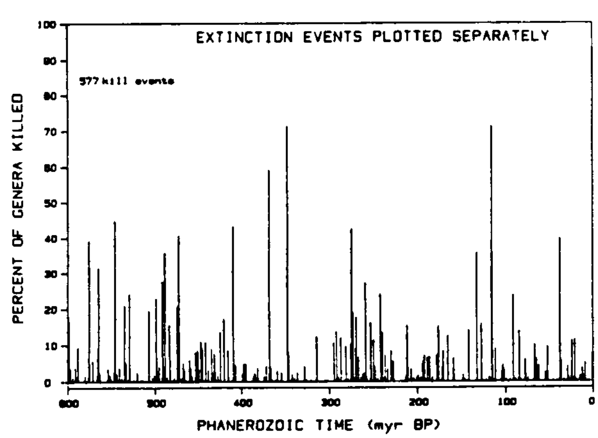

Figure 3. Simulated extinctions.

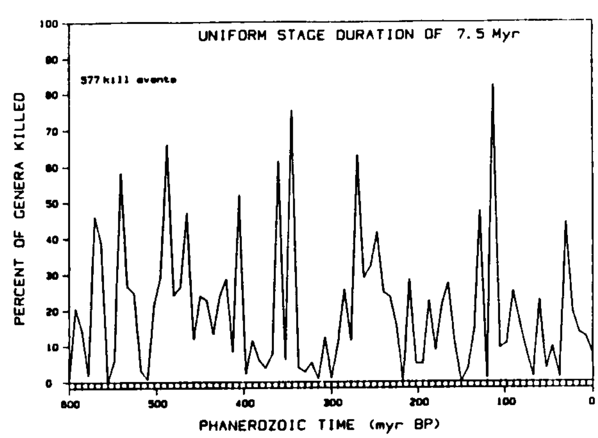

Figure 4. Extinctions grouped.