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PERIODIC COMETARY SHOWERS: REAL OR IMAGINARY?

R.A.F. Grieve, V.L. Sharpton, A.K. Goodacre. Earth Physics Branch, Department Energy, Mines and Resources, Ottawa, Canada K1A 0Y3, and J.B. Garvin, NASA - Goddard Space Flight Center, Greenbelt, MD 20771, U.S.A.

Since the initial reports in 1980, a considerable body of chemical and physical evidence has been accumulated to indicate that a major impact event occurred on earth 65 million years ago. The effects of this event were global in extent and have been suggested as the cause of the sudden demise or mass extinction of a large percentage of life, including the dinosaurs, at the end of the geologic time period known as the Cretaceous. Recent statistical analyses of extinctions in the marine faunal record for the last 250 million years have suggested that mass extinctions may occur with a periodicity of every 26 to 30 million years. Following these results, other workers have attempted to demonstrate that these extinction events, like that at the end of the Cretaceous, are temporally correlated with large impact events. A recent scenario suggests that they are the result of periodic showers of comets produced by either the passage of the solar system through the galactic plane or by perturbations of the cometary cloud in the outer solar system by a, as yet unseen, solar companion. This hypothesized solar companion has been given the name Nemesis.

The implications of this scenario of periodic cometary showers go beyond their suggested potential to regularly reshape the evolution of the terrestrial biosphere. In fact, it has been suggested that such showers may be responsible for modulating changes in global sea level, various types of tectonic activity and reversals in the earth's magnetic field. If such a periodic extraterrestrial driving force is indeed responsible for such a wide variety of related biological and geological changes on earth, then its recognition and acceptance would rival plate tectonics in terms of revolutionizing geologic sciences.

Since this imaginative hypothesis has such far-reaching and exciting implications, it deserves to be examined carefully. Many of the arguments calling for periodic cometary showers result from model astrophysical calculations, which were generated out of the desire to account for the apparent periodicity of the extinction record. The only offered evidence with a physical basis is from the ages of known terrestrial impact craters. It has been suggested that, as required by this hypothesis, the terrestrial cratering record shows a periodicity similar to that of the marine extinction record. At face value, this would appear to be supportive evidence. However, there are problems in the application and interpretation of statistical methods of searching for periodicities in the terrestrial cratering record.

The record of terrestrial cratering is woefully incomplete. Unlike the surface of the moon, the earth's surface retains relatively few recognizable impact craters. This is the direct result of the presence of oceans, which retain no known record of cratering, and such processes as erosion, deposition and tectonism which serve to remove, mask and destroy those craters on the land surface. For example, recent analyses indicate that even in geologically stable areas but under the unfavorable circumstance of glaciation, a 20 kilometer diameter impact crater may be removed as a recognizable geologic structure in as short a geologic time period as 120 million years.

Compounding the problem of crater retention is the problem of crater recognition. The search for terrestrial impact craters and their study is a relatively new facet of geologic sciences and owes much to the recent exploration of the planets, which has emphasized impact cratering as an important geologic process in planetary history. Few systematic searches for impact craters have been carried out. Impact craters are often found by chance following the discovery of an unusual circular feature on an aerial or space photograph or on a geologic map. The current inventory of terrestrial craters stands at slightly over 100 with two or three new discoveries generally being made each year.

In addition, the entire sample of known craters is not suitable for statistical analysis. Only those structures with well-constrained ages for their formation can be used to search for periodicities. Here again, there are problems. The restriction to well-constrained ages reduces the number of craters available for analysis. The most reliable age estimates for impact events are supplied by isotopic analysis of the original target rocks melted by the intense heat accompanying the high shock pressures generated on impact. This melting causes a resetting of the isotopic clocks. Even when available, however, such age estimates are not without problems in interpretation; particularly, if the melt rocks contain unmelted fragments of the target which have not had their isotopic systems completely reset. At some craters, different isotopic dating methods have yielded different ages. At others, no isotopic dating has been undertaken and the "well-constrained" age is based on the occurrence of fossils in sediments filling the crater depression. These latter ages can also be unreliable. The database of crater ages is constantly being upgraded and refined and there have been cases in recent years where new revised age estimates have differed considerably from previous estimates. There are inherent dangers, therefore, in accepting a generalized listing of crater ages without close scrutiny for use in sophisticated statistical analyses.

Problems with the completeness of the cratering record and reliable ages not withstanding, an updated listing of known craters with diameters greater than 5 kilometers and relatively reliable ages of between 0 and 250 million years has been compiled. This data set of 26 craters was analysed for periodicities. The problem is that a number of statistical periodicities can be defined. For the entire database there are two periods; a period of approximately 18.5 million years with the first peak at 2 million years occurs, as does one at approximately 29.5 million years with the first peak at 9.5 million years. If one restricts the analysis to the 20 craters with isotopic ages, in the belief that these age estimates are likely to be more accurate, then only the 18.5 million period is present. If the craters with ages less than 5 million years are omitted, based on the argument that young craters are best preserved and most easily recognized and thus they may bias the sample, then a period of 21 million years with the first peak at 15 million years can be defined. If the database is restricted to the 17 craters occurring on the geologically stable central portions or cratons of N. America and Europe, where there have been active programs to search for craters and where the database may be the most complete, the most dominant period is approximately 13.5 million years. Some other subsets of the data fail to indicate periodicities. These various statistical periodicities with different times for the onset of the first peak raises the question of which, if any, have a real physical significance?

Tests with a series of random numbers indicate that, for the threshold value of the statistic used to detect the above periodicities, it is possible to define a periodicity one time out of four. In addition, relatively small changes in the ages of some of craters are sufficient to change the dominant period or drop previously defined periods below the threshold of significance. It would appear, therefore, that the statistical support for these periodicities is not particularly strong.

This conclusion would seem at odds with previous claims that the odds of defining a periodicity in the cratering record are one in a hundred. However, these claims are for a periodicity coincident with that suggested for the marine extinction record. In the present analysis, the concern is with the chances of defining any periodicity regardless of its value. The ability to derive a periodicity of choice depending on the database used makes statements regarding periodic impacts and their relation to extinctions less than categorical. They require additional evidence above an apparent statistical coincidence based on the less than ideal record of known crater ages on earth.

There is, in fact, some additional evidence that can be used to address this problem. The initial argument used to call for a major impact at the end of the Cretaceous was the discovery of enrichments in so-called siderophile elements in the boundary clay layers. These elements have an affinity for iron and are depleted in the earth's crust, having been scavanged by the earth's core. This is not the case for some types of meteorites which never underwent a core-forming event. By examining the relative abundances of various siderophile and other elements in impact melt rocks, it has been possible in recent years to identify the type of projectile that formed some terrestrial craters. Although open to interpretation in some cases, due to chemical weathering and the fact that some of these meteoritic elements occur at levels of abundance of a few parts per billion or less, it appears that several of the craters used to define periodicities were formed by different types of bodies. This is not what would be expected if they were all formed by periodic showers of comets.

Although the cratering record may be relatively unsuitable for detailed statistical analysis, it has been possible to estimate the average cratering rate by restricting the analysis to large craters, diameters greater than 20 km, with relatively young ages, less than 120 million years old, occurring in the stable and well-studied N. American and European cratons. The estimated rate is equivalent to that calculated independently from observations on earth-crossing asteroidal bodies known as Apollos. The craters used to calculate a terrestrial cratering rate are in many cases the same craters used to call for periodic cometary showers. If they were formed in fact by comets then where are the large craters formed by Apollos, which are well known to have the potential to form craters on earth? Although there are large uncertainties attached to these rate estimates, due to concerns about completeness of search, the coincidence of the crater-derived and Apollo-derived rates would suggest that the simplest explanation is that most of the craters were in fact the result of the impact of Apollo bodies, not the suggested cometary showers.

In summary, the question of the reality of periodic cometary showers can not be answered by statistical arguements alone. It requires additional data involving the expansion and upgrading the database on terrestrial craters. The discovery of additional craters, more precise age estimates and analyses for projectile composition would reduce some of the present uncertainties. The more general question of the relationship between large-scale impact and biological extinctions is better addressed through additional detailed studies of the faunal record and searches for indications of large-scale impact at the precise time period of an extinction event. Given the present status of knowledge, we would caution against the general acceptance of the hypothesis that the earth was subjected to periodic cometary showers which exerted an extensive control over biological and geological evolution. Exciting although this hypothesis may be, the cited evidence is open to interpretation and in some cases favors the alternate, more traditional view that the bulk of terrestrial craters were formed by the impact of asteroidal-like Apollo bodies. Whether or not large-scale extraterrestrial impacts have exerted some influence over the evolution of the terrestrial biosphere and geosphere will undoubtedly be the subject of much future work and debate. Whatever the answer, these studies and hypotheses serve to remind us that the earth does not exist in isolation but may be subjected to external processes beyond those generally considered relevant to earth evolution.