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A SEARCH FOR EVIDENCE OF LARGE BODY EARTH IMPACTS ASSOCIATED WITH BIOLOGICAL CRISIS ZONES IN THE FOSSIL RECORD

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Were the Earth's great biological catastrophes caused by impacts of asteroids or comets?

Background

Five years ago, a University of California-Berkeley team (Luis Alvarez, Walter Alvarez, Frank Asaro, and Helen Michel) reported a discovery and a hypothesis that have had a dramatic effect on the way we think about the natural history of the earth--how the present plant and animal species developed, how others completely died out, etc. They were studying rock samples from strata in the neighborhood of the Cretaceous-Tertiary boundary, that is, strata that were deposited at the time of the great extinction 65 million years ago that marked the end of what Earth scientists have labeled the Cretaceous period. The extinction had wiped out many forms of terrestrial life, from land plants and microscopic marine life, to apparently, the dinosaurs. The rock strata sampled and studied by the Alvarez team were located near Gubbio, Italy, and at the time they were deposited, had actually been sea bottom. What these researchers found was that, exactly at the stratigraphic level corresponding to the extinction, a thin clay layer was greatly enriched, relatively speaking, in the rare element iridium. [Enriched in the other five elements of the platinum family as well, however, iridium can be measured more sensitively by the use of neutron activation.]

Iridium normally occurs at very low concentrations--a few parts per trillion--in the Earth's crust. It is much more abundant (100 to 10000 times more, though still rare) in solar system matter, but when the iron settled to the center of the molten Earth, the iridium went with it. Most meteorites contain the solar system abundance, whereas comets, which are thought to be mostly ice, probably range between solar system and Earth crustal iridium concentrations.

Taking into account these and other factors, the Alvarez team hypothesized that the excess iridium at the boundary came from a large asteroid-like object, of the order of 6 miles in diameter, that hit the earth. And, they also hypothesized that the impact of this object threw up a dust cloud dense enough and long-lasting enough to bring about the extinction of a wide variety of plants and animals, producing the unique break in the fossil record now called the Cretaceous-Tertiary boundary. Their observations on the samples from Italy were soon confirmed by similar observations on other (originally sea-bottom) samples taken in Spain, Denmark, and New Zealand, showing that the hypothesized catastrophe had been world-wide. The required impact crater has not yet been found, but this is not a fatal concern; the object might have hit at sea.

This radical asteroid-collision hypothesis provided a great wave of interest and controversy in the scientific community. Among the geological counter-arguments was one that was harder to dismiss: that all of the iridium-enriched samples measured up to that time had come from strata laid down at the bottom of the sea and, thus, that the iridium enrichment could have been caused by natural chemical processes in sea water, processes not yet well understood. The counter-argument was countered, in turn, by a discovery that we, in collaboration with USGS geologists, announced the next

year (1981). Taking samples from a drill core that spanned the Cretaceous-Tertiary boundary deposited under freshwater conditions at a site in what is now the Raton Basin of northern New Mexico and southern Colorado, we found the same iridium and platinum metals enrichment in a thin clay layer that corresponded with the boundary as defined by sudden radical changes in plant populations. In subsequent sampling we have confirmed the iridium enrichment at other freshwater-origin sites in the Raton Basin and in similar sites in Montana.

The Present Work

The geochemical evidence for a major impact catastrophe 65 million years ago is now firm and fairly widely accepted in the scientific community. But, the terminal Cretaceous event might not stand alone. Studies of the fossil record have shown other major extinctions in the Earth's biological history--around a dozen or so dependi on one's criteria--and other studies looking into the frequency of meteorite/comet impacts and how it varies with the object's size have shown that there ought to have been several terminal Crateceous-scale events in the approximately 600 million years for which we have fossil evidence of advanced biological forms.

Shouldn't it be possible, then, that some of these other well-established extinctions were also brought about by impact catastrophes? The work we report today is an attempt by the Los Alamos team and some of its collaborators to obtain answers to this question.

Following the Snowbird Conference on Large Body Impacts in October 1981 at Snowbird, Utah, we directed our primary effort to searching for geochemical signatures of large body impacts at extinction boundaries that predate the terminal Cretaceous event.

In collaboration with palentologic and stratigraphic experts, we have measured elemental abundances in samples collected across most of the recognized extinction boundaries. In several cases, we have performed these measurements on two or more widely-separated exposures of the same boundary, because we recognize that preservation of thin fallout beds is sensitive to erosion and mixing processes and, thus, the geochemical signature could be missing from some of the sections.

To date, we have made measurements across the following extinction boundaries: 1) Precambrian/Cambrian boundary (570 million years ago); 2) two trilobite crisis zones in the Upper Cambrian (515 and 520 million years ago); 3) Cambrian/Ordovician boundary (505 million years ago); 4) Ordovician/Silurian Asngillian extinction (440 million years ago); 5) Upper Devonian Frasnian/Famennian boundary (365 million years ago); 6) Permian/Triassic boundary-recognized by paleontologists as the largest extinction in the fossil record (245 million year ago); 7) Triassic/Jurassic boundary--a large Canadian impact structure has a similar date (about 210 million years ago); 8) a biological crisis in the Jurassic Toarcian Stage (about 185 million years ago; and 9) the Upper Cretaceous Cenomanian/Turonian Stage boundary that is characterized by marine black shales (about 90 million years ago).

Thus far, we have not found any firm evidence for the association of a large body impact with any of the above boundaries. In collaboration with an Australian geologist (Phillip Playford) and two Canadian geologists (Digby McLaren and Wayne Goodfellow) we have discovered a moderate iridium and platinum anomaly (15 to 20 times local background amounts) at the Frasnian-Famennian boundary zone in an Upper Devonian age reef complex in northwestern Australia. Our evidence indicates that bacteria enriched these elements and several others (some not prominent in meteorites) from seawater. It is difficult, however, to preclude the possibility that there were higher

concentrations of iridium and platinum in the ocean at that time due either to an impact or to nearby volcanism. Work in progress on a drill core from the reef complex might provide some further answers to this problem. We have also examined other Frasnian/Famennian boundary sequences exposed in New York and in Europe, but have found no indication of excess platinum-group elements. Again, we can not rule out possible lack of preservation at those sites.

Reports of iridium anomalies at the Precambrian/Cambrian and Permian/Triassic boundaries have added fuel to the recent "Death Star" hypothesis that suggested extinctions were caused by cyclic swarms of comets. However, in duplicate sets of samples from both boundaries we were unable to reproduce the high concentrations of iridium reported by others; we measured very low Earth crustal amounts that ranged from 1 to 35 parts per trillion.

In summary, our measurements at the Cretaceous-Tertiary boundary in freshwater deposits from New Mexico to Montana support the Alvarez hypothesis of a large body impact at that mass extinction horizon. Thus far, we have not found any evidence for the association of a large body impact with any of the major extinction boundaries that predate the terminal Cretaceous event. And recent hypotheses that suggest extinctions were caused by periodic (26 to 33 million year cycles) comet swarms are not supported by our measurements. However, one should accept our negative results with some caution, because preservation of thin fallout beds is sensitive to erosion and mixing processes, thus the geochemical signature might be missing from some of our sampled sections. Although the amount of iridium deposited on the Earth's surface from a comet impact might be considerably less than from a similar size asteroid, our detection methods for iridium are so sensitive we can pick up iridium concentration changes only one percent as large as the world-wide anomaly at the Cretaceous-Tertiary boundary.