ENVIRONMENTAL EFFECTS OF LARGE IMPACTS: WAS THE END-CRETACEOUS EVENT TYPICAL?

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Introduction: Over 25 years of intense study of the Cretaceous-Tertiary (KT) or Cretaceous-Paleogene (KP) boundary layer has yielded a rich harvest of ideas about the global catastrophic effects of impacts by large extraterrestrial bodies, be they asteroids or comets. Effects that have been proposed include 1) the generation of large tsunami-like waves that ravaged coastal and shelf areas throughout the region adjoining today's Gulf of Mexico; 2) rapid heating of the upper atmosphere by the re-entry of ejecta (primarily spherules), leading to global wildfires; 3) the injection of enough fine dust and/or sulfate aerosol into the atmosphere to cause global cooling over a longer time span; and 4) one of the greatest mass extinctions in Earth history. These conclusions have come almost entirely from the study of the ejecta layer formed during the end-Cretaceous event and the sedimentary strata that host it [1 and references therein]. It is tacitly assumed by many researchers that impacts by objects comparable in size to the end-Cretaceous impactor had similar environmental effects throughout Earth history. The best way to test this assumption is to examine ejecta layers from other comparably large impacts and see if they are similar in nature.

KT versus other impacts. The first clue that the end-Cretaceous event may be atypical is the fact that no other ejecta layer of comparable size or complexity has been linked to a mass extinction, despite years of intensive searching. The problem is not a lack of ejecta layers - a dozen or more formed by impacts roughly comparable in size to the end-Cretaceous event have been discovered in the last few decades, most of which share a profusion of millimeter-scale spherules of former silicate melt [2,3]. Since most of these impacts happened in the Precambrian, the lack of Metazoan fossils makes it difficult to determine whether they did serious damage to the biosphere, but it can be done. For example, the ejecta layer formed by the Neoproterozoic Acraman impact appears to coincide stratigraphically with a marked increase in the diversity of acritarchs [4], the opposite of a mass extinction.

In addition to biotic changes, the nature of the ejecta and the relationship of the layers to surrounding strata can be compared to the KT boundary layer to assess whether they were comparable in other respects. In fact, it appears that most of the Precambrian layers differ from the end-Cretaceous layer in significant ways. For example, differences in the spherules suggest the Precambrian impactors struck target rocks with different compositions. Specifically, many of the Precambrian spherules show internal textures that are a close match for those of natural and artificial basalts [5,6]. Crystallized KT boundary layer spherules rarely show such textures; they typically contain dendritic clinopyroxene (CPX) crystals instead [1]. Since 90% or more of the mass of impact spherules is thought to be terrestrial in origin, this suggests the Precambrian impacts hit basaltic target rocks, whereas we know the end-Cretaceous impactor hit a combination of carbonates, sulfate evaporites, and continental basement rocks. The crystallization of CPX has been attributed to the formation of a hybrid melt relatively rich in Ca and low in silica. The only impact spherules that show comparable textures belong to the Eocene "CPX layer" [7]. It was probably generated by the Popigai impact, which also happened in carbonates overlying continental basement rocks. Interestingly, the Eocene CPX layer does not coincide with a major mass extinction, nor have long-lasting environmental effects been attributed to it. In addition, there is also controversy as to whether the Precambrian spherules originated as ballistic melt droplets or condensed from rock vapor [5,6].

Precambrian impacts. Finally, the features of many of the Precambrian ejecta layers suggest their regional environmental effects were similar to those of the end-Cretaceous event, but that may had little in the way of long-lasting environmental effects. Most of the Precambrian layers per se contain sedimentary structures indicating they were deposited during unusually high-energy events involving impact-induced waves and/or currents [5,8]; in this, they are very similar to the KT boundary layer in the Gulf region. Had the impacts caused large-scale, longer term changes in Earth's surface environments, one would expect the ejecta layers to coincide with major lithologic shifts in the stratigraphic record. A few of the Precambrian layers are close to such shifts, e.g., the 2.63 billion year-old spherule layer near the top of the Neoarchean Jeerinah Formation in the Hamersley Basin of Western Australia is 2 meters below the base of what is arguably the first large banded iron formation on Earth [9]. However, other Precambrian ejecta layers occur in the midst of continuous successions with no apparent difference between strata above and below the layers, e.g., in the Wittenoom Formation and Dales Gorge banded iron formation in the Hamersley Basin [9] or the Monteville Formation in the roughly contemporaneous Griqualand West Basin of South Africa [10].

In summary, the end-Cretaceous event has been a fascinating topic for study, but comparisons with other ejecta layers in the stratigraphic record raise the possibility that it was a “one-off” whose environmental effects may have been different from other impacts, even those comparable in size and Phanerozoic in age. At a minimum, inferences about the environmental effects of large impacts should not be extrapolated uncritically solely on the basis of the end-Cretaceous event. Equally intensive study and modeling of distal ejecta layers from a number of other large impacts are needed before we can adequately assess how “typical” the end-Cretaceous event really was.

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