After the Fall

Although the dust was bad, the chemical fallout from the Cretaceous-Tertiary impact was worse—much worse

If one assumes that the mass extinctions at the Cretaceous-Tertiary boundary were really caused by the impact of a large comet or asteroid some 65 million years ago, as the evidence increasingly suggests, then conditions at that time were not just bad. They were ghastly. Recent computer models by atmospheric scientists Ronald G. Prinn and Bruce Fegley of the Massachusetts Institute of Technology indicate that the aftermath of such an impact could have included a year of darkness under a smog of nitrogen oxides; waters poisoned by trace metals leached from soil and rock; and global rains as corrosive as battery acid.

"The problem isn't to kill species off," said Prinn as he described the findings at the recent AAAS meeting in Boston. "The problem is to think of safe havens where anything could have survived."

Prinn explained that his current work with Fegley is actually a much revised and expanded version of a model that he, John Lewis of the University of Arizona, and their collaborators first put forward in 1982. Their basic argument was and is that the chemical effects of the impact were at least as important as the better known physical effects, such as dust, smoke, and a nuclear winter–style chilling of the global climate.

The new calculations bear that out, said Prinn. In an effort to bracket the possibilities, he and Fegley looked at two plausible, but extreme models for the impacting body. On the low end they assumed a rocky-iron asteroid with a radius of 3 kilometers, a mass of 500 billion tons, and a velocity of 20 kilometers per second. (The latter value is typical of objects orbiting in the inner solar system.) On the high end they assumed a new, ice-rich comet coming in from the far outer solar system with a radius of 14 kilometers, a mass of almost 13 trillion tons, and a velocity of 65 kilometers per second. As comets go this latter object is huge, Prinn conceded. Nonetheless, the masses were chosen so that the projectiles would each contain enough iridium and osmium to explain the famous anomalies in the Cretaceous-Tertiary boundary layer.

With either projectile, said Prinn, the impact itself would have produced an explosion far beyond the capabilities of all the nuclear weapons currently on Earth. A plume of vaporized rock and water would have risen beyond the stratosphere. An atmospheric shock wave would have begun spreading outward from ground zero at roughly five times the speed of sound. The air would have been compressed and heated to temperatures on the order of 2000 K, hot enough that the nitrogen in it would have literally begun to burn. Within hours the atmosphere would have carried gigatons of NO and NO_2. And within days the rain clouds would have been filled with nitrous and nitric acid.

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This chemical fallout could have affected the biosphere in at least three ways, said Prinn. First, enough nitrogen oxides would have been produced under either impact scenario to have contaminated the global atmosphere for a year or more. In the case of the comet, in fact, the reddish-brown compounds would have been dense enough to block the sun completely and thus to choke off photosynthesis. (This would have come in addition to any blockage by post-impact dust and smoke.) At the same time, the oxides would have been directly toxic to growing plants and to air-breathing animals such as the dinosaurs. This factor alone might account for some of the curious selectivity of the Cretaceous-Tertiary extinctions, said Prinn. Plants, which could have survived in the form of seeds and roots, were relatively unscathed. But the dinosaurs, which had to endure both starvation and asphyxiation, were wiped out.

The second threat, of course, was acid rain. In the immediate aftermath of the asteroid impact the local rainfall would have had a pH of 0 to 1, which is comparable to battery acid. Some 2 years later, after the nitrogen oxide cloud had been thoroughly mixed with the remainder of the atmosphere, the global rainfall would have been diluted to a relatively benign pH of 4, slightly better than the worst acid rain of today. In the case of the cometary impact, however, dilution would have been ineffective: 9 months afterwards, the pH of rainfall would have been 0 to 1 worldwide.

Obviously, said Prinn, rain of this corrosiveness would have been devastating wherever it fell. But it would have fallen particularly hard on shallow coastal waters and the upper layers of the deep ocean: so much acid would have collected in those regions that calcium-carbonate-shelled organisms would have begun to dissolve. Indeed, said Prinn, this is generally what the fossil record seems to show. Calcareous organisms such as the spiral-shelled ammonites died out in vast numbers at the end of the Cretaceous. And yet silica-shelled organisms such as the diatoms, whose shells are more acid resistant, did relatively well.

On land, meanwhile, there actually would have been a few havens, said Prinn. Animals living in burrows may have been protected, particularly if the soil and surface rock of the region were rich in limestone. Conceivably this could account for the survival of the mammals, most of whom were small creatures that may well have nested underground. By the same token, freshwater lakes in limestone-rich regions would have been buffered against the worst of the acid. And indeed, lake-dwelling creatures did generally survive.

Finally, said Prinn, acid rain leaching through soil and rock would have polluted the post-impact environment with yet a third threat: toxic trace metals. The possibilities include beryllium, aluminum, mercury, lead, and a variety of others. The actual magnitude of this effect is difficult to calculate, he said, and unfortunately the geologic evidence for it will be difficult to find. On the other hand, he said, J. Douglas Macdougall of the Scripps Institution of Oceanography has recently pointed out that sediment cores from the Deep Sea Drilling Project show a sharp spike in the strontium-87 to strontium-86 isotope ratio precisely at the Cretaceous-Tertiary boundary. Furthermore, said Macdougall, since the strontium ratio in continental crust is higher than it is in the ocean, such a spike is exactly what one would expect from a massive acid-rain event. Indeed, no other explanation seems able to account for the spike at all. ■

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ADDITIONAL READING

R. G. Prinn and B. Fegley, Jr., "Bolide impacts, acid rain, and biospheric traumas at the Cretaceous-Tertiary boundary," *Earth Planet. Sci. Lett.* **83**, 1 (1987).

J. D. Macdougall, "Seawater strontium isotopes, acid rain, and the Cretaceous-Tertiary boundary," *Science* **239**, 485 (1988).

R. Kerr, "Was there a prelude to the dinosaurs' demise?" *ibid.*, p. 729.