Asteroid Theory of Extinctions Strengthened

An asteroid may well have hit Earth at the close of the dinosaur age, but how that impact might have affected life is still obscure

The abrupt disappearance of all the dinosaurs about 65 million years ago, along with perhaps half of the plants and other animals, has been one of the great geological mysteries. Clues to the cause of these extinctions have been scarce and open to innumerable interpretations. That may be changing. Last year, a group at the University of California, Berkeley, claimed to have found chemical traces of what may have been the ultimate cause of all the extinctions—dust from the impact of a 10-kilometer-wide asteroid that hit Earth at the geological instant of extinction.

Since last year, the Berkeley group and investigators at other laboratories have gathered evidence confirming the extraterrestrial origin of the traces of exotic metals that had been found. They have also shown that the chemical clues are scattered worldwide in six areas in Europe, Europe's antipode New Zealand, and the central North Pacific. With that kind of evidence piling up, researchers now believe that any explanation of the extinctions must also account for the new geochemical evidence.

In spite of the mounting evidence, there are suggestions that an asteroid impact need not be invoked and that the geochemical anomalies could be a by-product of the extinctions rather than evidence of their cause. None of these alternative explanations have gained much support yet, but specialists in such diverse fields as paleontology and the mechanics of impact cratering have serious reservations about how an asteroid could have selectively exterminated some species and not others in the way the fossil record seems to suggest. In fact, resistance among many paleontologists to a purely catastrophic cause, an explanation which has been out of vogue for 200 years, is so high that they are willing to make only a small concession to the mounting geochemical evidence supporting an asteroid impact. Perhaps, they say, the cause was a combination of gradual environmental changes punctuated by an asteroid impact.

The first clue to a possible role for an asteroid in extinctions was a serendipitous discovery. Luis Alvarez, a physicist at the University of California's Lawrence Berkeley Laboratory, his son Walter Alvarez, a geologist at the University of California, Berkeley, and Frank Asaro and Helen Michel, analytical chemists at Lawrence Berkeley, were trying to find out how fast sediment collected on the sea floor 65 million years ago, which was the time of the extinction of many of the microscopic, floating organisms of the sea. The disappearance of these planktonic species in the fossil record has been used to mark the boundary between the Cretaceous period, when the last of the dinosaurs lived, and the subsequent Tertiary period. The boundary is also often marked by a thin layer of clay separating the sediments of the Cretaceous from those of the Tertiary.

Luis Alvarez had thought that he might be able to measure the variable accumulation rate of planktonic skeletons and clay across the Cretaceous-Tertiary boundary by using the steady rain of cosmic dust that settles to Earth's surface as a reference. Alvarez chose the element iridium, which is scarce on Earth's surface but relatively abundant in meteorites, as a chemical tracer for the extraterrestrial dust. The intended experiment failed, as the researchers might have predicted if they had been aware of earlier sediment analyses of iridium, but, unlike earlier workers, the Berkeley group stumbled on a perplexing anomaly. They found that the clayey component of the boundary layer at Gubbio, Italy, is about 30 times richer in iridium than the sediment above or below it. They found an even greater enrichment in the boundary layer in Denmark.

Their announcement that part of the iridium-rich layer was possibly extraterrestrial caused quite a stir in the press last year, partly because some reporters mistakenly assumed that a supernova had wiped out the dinosaurs. Although iridium has since been proven a reliable tracer for extraterrestrial material, it is now certain that a blast from a supernova did not deposit the iridium in the Cretaceous-Teritiary boundary layer. Three groups of investigators (the Berkeley group, R. Ganapathy of the J. T. Baker Chemical Company in Phillipsburg, New Jersey, and Jan Smit of the Geological Institute in Amsterdam with J. Hertogen of Fysico-Chemical Geology in Leuven, Belgium) looked for evidence of a supernova, but found none of the unusual isotopic abundances that would be expected if some of the material had been synthesized in a nearby supernova.

On the basis of this negative evidence, the Berkeley group revived Harold Urey's 1973 speculation that the impact of a comet ended the Cretaceous, but they added a few twists. For one, they suggested an asteroid rather than a comet. Enough asteroids are known to cross Earth's orbit that one 10 kilometers across, large enough to account for the concentration of iridium at Gubbio, would hit Earth every 100 million years on the average. When it hit Earth, probably while traveling at roughly 90,000 kilometers per hour, part of its 100 million megatons of kinetic energy could have been consumed in throwing tens of quadrillions of tons of pulverized rock into the stratosphere, according to the theory. The dust would be so thick for several years that the sunlight reaching the surface of Earth would equal only 10 percent of full moonlight. Plants would die in the sea and on land, food chains would be shattered from the bottom up, and the extinctions would follow. The 175-kilometer-wide crater left by the asteroid may be somewhere beneath the sea because no such crater has been found on land.

The first premise of this hypothesis, that the boundary layer at Gubbio and in Denmark is enriched in meteoritic material, is widely accepted. No one can think of a likely terrestrial source for that much iridium. Other rare elements are also enriched. Ganapathy analyzed the Danish boundary layer for iridium and eight other elements enriched in meteorites. Most of these elements occurred in proportions similar to those of a typical meteorite. In order for these metals to have originated in crustal rocks, some geologic process would have had to concentrate the osmium, iridium, palladium, nickel, and gold 10 to 1000 times to reach meteoritic proportions.

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The anomalous elemental compositions first reported from Italian and Danish samples not only match meteoritic compositions, but they now appear to be distributed worldwide. The Berkeley group has identified anomalous enrichments at the Cretaceous-Tertiary boundary at five sites in Italy and in Denmark (where Ganapathy confirmed it), in New Zealand through work with Dale Russell of the National Museum of Natural Sciences in Ottawa, and at two sites in northern Spain in association with Michael Arthur of the U.S. Geological Survey (USGS) in Denver. Smit and Hertogen also found the boundary layer in southeastern Spain to be enriched in meteoritic material. And Frank Kyte, Zhiming Zhou, and John Wasson of the University of California at Los Angeles report finding an enriched layer in a central North Pacific core recovered during the Deep-Sea Drilling Project.

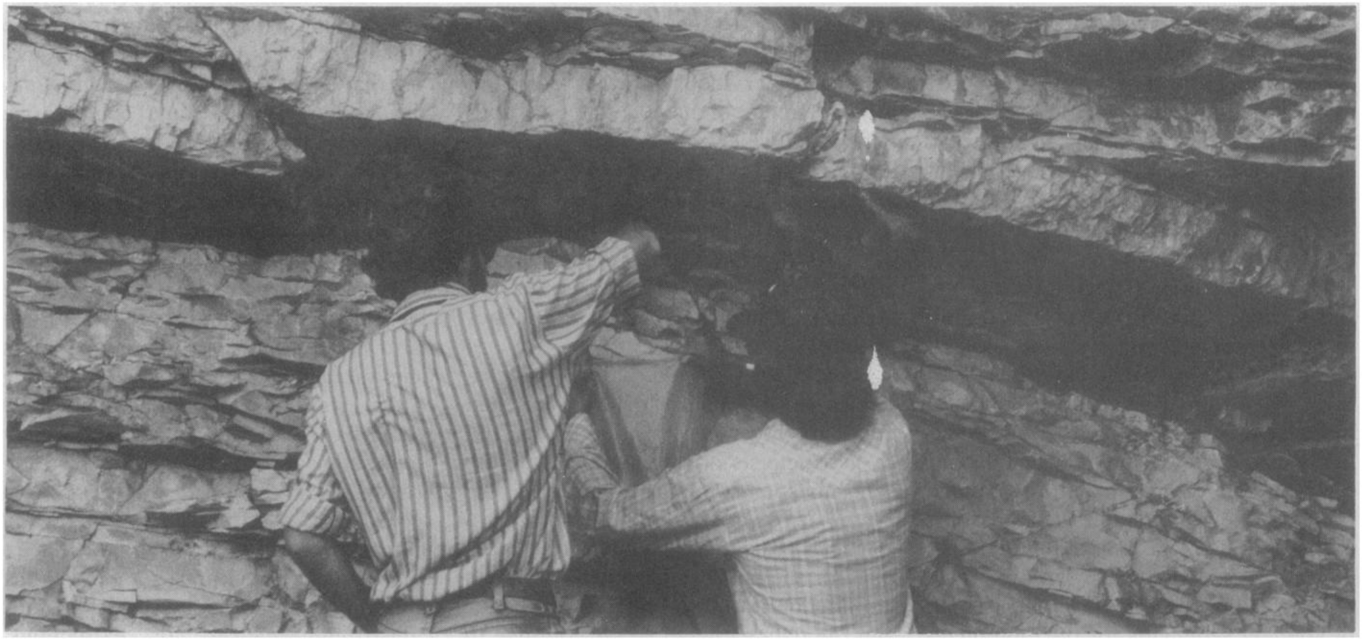
Although the widespread distribution of anomalous boundary layers is seen by many as strong support for something big having fallen out of space at the end of the Cretaceous, others see it as a problem for the asteroid impact theory in particular. Some specialists in the study of impact cratering believe that the boundary layers are too rich in meteoritic material to contain dust that settled out of the stratosphere after an asteroid impact. Even hundreds of trillions of tons of asteroid would be so diluted, they say, by the terrestrial rock churned up on impact that the chemical traces of the asteroid should be faint if recognizable at all. Actually, the clay of the boundary layers examined so far contains at least several percent meteoritic material, and the Danish clay is almost 10 percent meteoritic. In contrast, notes Wasson, lunar soils that have been receiving ejecta from meteorite impacts, including the huge mare-forming impacts, for more than 4.2 billion years contain less than 4 percent meteoritic material.

The Berkeley group concedes that the Danish layer is a problem. It is eight times too rich if they assume that the asteroid kicked up 60 times its own weight of crustal rock, a value which seems to work for the other sites. But the problem may be more troublesome than that. Richard Grieve of Canada's Department of Energy, Mines, and Resources in Ottawa believes that the 60 to 1 ratio is probably low. The rock of an asteroid might be diluted by as much as 1000, he says. Thomas Ahrens of the California Institute of Technology favors a ratio of 10,000 to 1 or more. As evidence of likely high dilutions, Grieve and others point to the difficulty of finding meteoritic chemical signatures of known craters on Earth. Even in the solidified puddle of rock that marks a large impact, the meteoritic content is usually only about 1 percent. Adding their reservations about dilution factors to their uncertainty about how an impact might toss enough fine dust into the stratosphere, cratering specialists still regard the details of the impact theory as a bit dubious. Perhaps, some say, the asteroid destroyed itself in midair and never hit the ground.

Another group of doubters, associated with no single specialty, wonder if there was any asteroid at all. They agree that the boundary layer is enriched in meteoritic material worldwide but suggest that the cosmic material that slowly drifts onto the surface of Earth, which would normally be highly diluted by sediment, was somehow concentrated at the Cretaceous-Tertiary boundary.

Dennis Kent of the Lamont-Doherty Geological Observatory has suggested that ocean currents could have carried away most of the sediment deposited at about the time of the extinctions and left the remainder enriched in extraterrestrial material. Such a winnowing process could work, experts say. Microscopic spherules, thought to be swept off meteorites as they pass through the atmosphere, have been recovered from deep-sea sediments since the historic *Challenger* oceanographic expedition of the 1870's. Sufficiently strong ocean currents could remove the fine sediment, leaving the larger, denser spherules behind. Panning for nuggets of gold works the same way. Such winnowing is known to concentrate larger sediment particles such as sand on even the deepest sea floor. And the geologic strata laid down at the Cretaceous-Tertiary boundary often show signs of missing sediment, perhaps because of currents that were induced by climatic changes.

Winnowing does have some problems,



Sampling the Cretaceous-Tertiary boundary at Petriccio, Italy

The clay layer deposited 65 million years ago at the time of the marine mass extinction is in the recess below the overhanging limestone. The sedimentary rock below it is from the Cretaceous period, the time of the last dinosaurs. Above it are younger sediments of the Tertiary period. An enrichment of meteoritic material was found in the boundary clay layer here and at four other sites in Italy. [Photo: Walter Alvarez] however. Donald Brownlee of the University of Washington and Ganapathy have found that large spherules (greater than 250 micrometers) comprise only one-millionth of a percent of a Pacific deep-sea sediment. Smaller spherules are more abundant, but it is unclear whether they contain enough mass to make winnowing practical. Another problem is the global distribution of the anomalies. Michael Ledbetter of the University of Georgia notes that winnowing of deep-sea sediments today is generally limited to the western edges of major ocean basins where swift bottom currents are concentrated. It would be surprising, he says, if six areas around the globe had the same strong currents at the same time.

A second suggested way of producing the observed enrichments without an asteroid is the concentration of iridium and the other elements by organisms in the sea. Kenneth Towe of the National Museum of Natural History in Washington, D.C., has suggested that, if plankton did concentrate these elements, then they might carry them to the bottom after a mass extinction. There, oxidation would destroy the organic matter and leave the metals in a thin, rich layer. The iridium content of plankton is not known, but Towe contends that many of the elements enriched at the boundary are also known to be enriched in living matter. A major problem for this proposal, Ross Heath of Oregon State University says, is explaining why the relative proportions of these metals in plankton should resemble those of meteorites.

A third concern of some researchers is that a decrease in the rate at which sediment accumulated on the sea floor 65 million years ago could have increased the concentration of meteoritic material in the sediments. A decrease almost certainly occurred when the calcium carbonate skeletons of plankton stopped falling to the bottom after the plankton's extinction. Kent has pointed out that the effects of such a decrease can be studied by correcting the iridium concentration of younger sediments for the diluting effect of their calcium carbonate. If the iridium concentrations of sediments less than 2.5 million years old, as determined by James Crocket and H. Y. Kuo of McMaster University, are calculated as if the sediments contained only clay and no calcium carbonate, they appear to contain as much iridium (about 8 parts per billion) as the enriched boundary layer at Gubbio. Thus, Kent argues, high amounts of iridium per weight of clay need not always be associated with an asteroid impact or extinctions.

Two other sets of sediment analyses, the only others for iridium available, suggest that slow sedimentation alone cannot greatly increase iridium concentrations. In one investigation Ganapathy found the iridium content of a slowly accumulating deep-sea clay from the mid-Pacific to be 0.8 ± 1.2 parts per billion. Such deep-sea sediments contain little or no calcium carbonate, only clays washed off the continents. In the other study, John Barker, now at Goddard Space Flight Center, Greenbelt, Maryland, and Edward Anders of the University of Chicago analyzed deep-sea clay sediments from five sites around the Pacific. They found maximum concentrations of iridium of about 0.4 part per billion and similar concentrations of osmium. They also found that the lower the sedimentation rate, the higher the iridium content, as doubters of the asteroid theory would predict. But the most slowly accumulating sediment, having a rate of about 0.5 millimeter per thousand years, had an iridium content of only 0.2 to 0.6 part per billion, equivalent to 0.1 percent meteoritic material if all the iridium was extraterrestrial. A few sediments are known to accumulate at one-half to one-third the rate at this site, but the meteoritic content of the Cretaceous-Tertiary boundary samples is 20 to 100 times greater.

None of the three alternatives to an asteroid as the cause of the enriched boundary layer has been well received by geochemists or sedimentologists, the specialists most familiar with the processes involved. No other mechanism seems as reasonable to them as an asteroid. As one geochemist notes, "There's nothing quite so convincing as data," and the data gathered so far continue to support an encounter with an asteroid 65 million years ago. Lingering doubts should be resolved one way or the other as more samples are analyzed for iridium. The speculations of the Berkeley group have stimulated unprecedented interest in testing the asteroid theory, resulting in a flood of samples to be analyzed. Analyses are being made of other marine sediments at the Cretaceous-Tertiary boundary, terrestrial sediments of the same age, and sediments at other extinction boundaries.

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Whether dust thrown up by the impact of an asteroid led to the extinctions that occurred near the Cretaceous-Tertiary boundary is much less certain than the existence of the asteroid. While conceding that they will probably not be able to cast a deciding vote, some paleontologists are objecting to many of the details of the Berkeley group's hypothesis. "The [paleontological] evidence does not allow such a simple answer," says Norman Newell of the American Museum of Natural History.

The Berkeley group, which includes a geologist but no paleontologists, suggests that the connection between the asteroid and the extinctions was the blocking of the sun by dust from the impact. The planktonic plants would have succumbed quickly and taken the animals that they supported in the food chain with them, from microscopic foraminifera to the huge marine reptiles. The fossil record of the microplankton tends to fit this picture. Micropaleontologists have long thought of the rapid demise of so many species at the end of the Cretaceous as catastrophic. According to independent studies by Kent and Arthur, the planktonic foraminifera may have died out over about 10,000 years or less, a geological instant as compared to the millions of years over which some species have declined toward extinction. The Berkeley group did recognize one apparent inconsistency in the marine record—many invertebrates of the shallow continental shelf areas survived, perhaps by consuming detritus from rivers, they suggest.

Terrestrial paleontologists do not see the match between the Berkeley scenario and the fossil record as being as good on land as in the ocean. According to the asteroid theory, individual plants would have withered or died, but many would have avoided extinction by regenerating after the great darkness from seeds, spores, or roots. Any terrestrial animals that survived would have had to eat insects or decaying vegetation. While admitting a certain cultural bias against catastrophic causes for extinctions, many paleontologists firmly believe that the pattern of extinction, what survived and what did not, does not jibe with that expected to result from 2 or 3 years of darkness. Some researchers do not see the need for a catastrophe of any kind.

Prominent among the paleontological doubters are the paleobotanists. Leo Hickey of the National Museum of Natural History believes that the extinction pattern of land plants was the opposite of that expected from dust blocking the sun. According to his interpretation of the fossil record of plants, perhaps 70 to 80 percent of the species in western North America became extinct. Losses were particularly heavy to the north in Alaska, Canada, and northeastern Siberia. In the tropics, on the other hand, the decrease in the number of species was so slight that it may not be statistically significant. The same patterns of extinction have been independently determined by Robert Tschudy of the USGS in Denver and by David Jarzen of the National Museum of Natural Sciences in Ottawa.

If the entire globe were shrouded by dust, Hickey reasons, the less hardy tropical plants should have suffered the most rather than the least. Although data are not plentiful, the general opinion is that tropical plants or their seeds would be much less likely to survive several years of darkness, and the accompanying cold, than more northern species that regularly experience long, dark winters. Hickey and, he says, most of the paleobotanic community hold that the extinctions can best be explained as the result of a gradual climatic deterioration during the last few million years of the Cretaceous period that continued for 10 million years before conditions improved. "I'd love for it to have been a catastrophe," Hickey says, because it would make things simpler. "But my work doesn't show it. It looks like there is something to the asteroid hypothesis, but the damage [that it proposes] looks too great."

Researchers in other specialties are also comparing observed patterns of extinction with the Berkeley group's speculations. Some evidence runs counter to the sun-blockage theory, such as the minor changes among freshwater plants and animals. Paleontologists view the fossil record of some other groups, such as that of the mammals, as too incomplete to permit a strong statement one way or the other. They do not even agree on whether the dinosaurs met a sudden end. The strongest evidence for instantaneous extinctions remains the marine microfossils.

In the absence of a paleontological consensus, gradualism and catastrophism have until now coexisted with no overlap. Russell has been a prominent spokesman for a possible catastrophic cause of the Cretaceous-Tertiary extinctions. He finds no evidence of a gradual decline in the diversity of the dinosaurs, large or small, toward the end of the Cretaceous. The demise of the dinosaurs, as well as the other groups that succumbed, appears to have taken less time, Russell says, than can be reliably measured in the geological record, which is about 100,000 years or less. The duration of the extinctions, he argues, is much shorter than the environmental changes, such as climatic cooling, that others suggest as causes. Similarly rapid environmental changes have occurred over the past 2 million years as Earth swung between glacial epochs and warmer times, but no severe mass extinctions occurred. In fact, most researchers believe that none of the other four mass extinctions of the last 500 million years were clearly more severe or more rapid than that at the end of the Cretaceous.

Erle Kauffman of the University of Colorado has read the geological record a little differently. According to his view, most mass extinctions only appear to be instantaneous because of the incompleteness of the fossil record. Toward the end of the Cretaceous, Kauffman notes, sea level gradually fell hundreds of meters, draining the shallow seas over parts of the continents and exposing large areas of sediment to erosion. He explains that 80 to 90 percent of the sediments on the continents that might have contained informative fossils are missing part of the geologic record. The remaining record, such as it is, suggests gradual declines leading up to the boundary. The only exceptions are the deep-sea sediments, where the extinction of warm-water plankton having carbonate skeletons seems to have been extremely rapid, he says.

The causes of the Cretaceous-Tertiary extinctions, as gradualists see it, was a combination of environmental stresses that pushed species of one habitat after another to extinction. As sea level fell, probably in response to a slowing of seafloor spreading at mid-ocean ridges, seawater temperature, salinity, and oxygen content changed, and continental climates deteriorated. Similar but less severe episodes of extinction occurred during the Cretaceous, accompanied by the same kinds of environmental changes, Kauffman says.

Schemes involving gradual declines toward extinction have not required any sort of catastrophic event, but they may be beginning to accommodate one. Kauffman and many other paleontologists view the geochemical data supporting an asteroid impact as sound but still tentative. If the evidence eventually provides strong support for an asteroid impact in Earth's ocean 65 million years ago, it would have been "the straw that broke the camel's back," Kauffman says. It could have precipitated the rapid extinction of organisms living in or dispersing larvae through the warm surface waters. But extinctions on land and in some parts of the ocean would still have been caused by gradual environmental changes, he says.

Although more paleontologists would prefer a gradual over a catastrophic cause for the extinctions, paleontological evidence alone is not likely to resolve the question. The fragmentary geological record, imprecise measurement of geological time, and the extreme specialization of fossil studies work against it. Paleontologists faced a similar problem when the possibility of drifting continents forced itself upon them. In the end, marine geophysicists and geologists presented them with the answer that continents do move. Now, paleontological speculations based on geochemical evidence are stimulating an unprecedented burst of interest in the cause of mass extinctions. The difference again is that the new theory is obviously testable.

—RICHARD A. KERR

Manicouagan, a probable impact

Located in eastern Quebec, Canada, this structure is about 70 kilometers wide, 210 million years old, and filled by a lake that is here covered by snow. Manicouagan is less than half the size of the crater hypothesized to have resulted from the impact of an asteroid at the time of the Cretaceous-Tertiary extinctions. [Photo: NASA]