are capable of binding to MHC proteins.

For others, however, binding of antigen peptides occurs but the complex is not recognized by T cells. Complexes of foreign peptides and MHC proteins may also escape recognition if they happen to look like the self-complexes.

Immunologists think that T cells with a strong predilection for recognizing self-antigens are somehow eliminated in the thymus gland, the site of T cell maturation. Allen suggests that the cells get deleted if they encounter a self-peptide complexed with an MHC protein. "Conceptually, it's an appealing hypothesis, but we have to go and show it," he remarks.

His own work demonstrates that complexes of self-peptides and MHC proteins normally exist in the body. As Strominger points out, "The proteins of a cell are being degraded and resynthesized all the time." Cell peptides would therefore be available for complexing with MHC antigens, just as are the viral peptides that are synthesized in infected cells.

Complexes between an MHC protein and a self-peptide may also be at the root of graft rejection, according to Strominger. His group has found that mutations in an MHC protein affect its ability to participate in a graft rejection reaction the same way as they affect its ability to participate in a response to a viral antigen. The recognition event therefore appears to be the same in both responses, that is, a T cell interacting with a peptide bound to an MHC molecule.

What researchers would like to see next is a clear view of an antigen peptide in the MHC protein groove. The MHC protein analyzed by the Strominger-Wiley group contained something in its antigen-binding groove, but the resolution of the x-ray structure was not good enough to see what it was. A clear view could help resolve some of the issues about the structures of immunodominant peptides. Immunologists could see, for example, whether they bind in a helical configuration or in a more extended conformation.

Harden McConnell of Stanford University notes, however, that even this will not necessarily reveal the structural requirements for forming the complex between an antigen peptide and an MHC molecule. His work indicates that this complex undergoes a significant structural change after the binding event. The structure captured by x-ray crystallography will be final one, not the initial one.

Nevertheless, the studies of T cell pattern recognition are beginning to resolve some of the most fundamental issues of immunology, including immunodominance, tolerance, and graft rejection. ■ JEAN L. MARX

Huge Impact Is Favored K-T Boundary Killer

A large impact rather than a volcano is widely taken to be the primary agent of destruction at the end of the dinosaur age

Snowbird, Utah

NO ONE ASKED FOR A SHOW OF HANDS, but a vote among those attending the conference on Global Catastrophes in Earth History* here would have given a clear-cut victory to an asteroid or comet impact as the most likely explanation of the mass extinction 66 million years ago. That was when the last of the dinosaurs died out.

For several years a small group of researchers has been advocating millennia of volcanic eruptions of previously unimagined power as an alternative agent of destruction. The geologic record is being misread, this group claims, by those insisting that a large impact instantly laid down the thin layer of exotic sediment found in the late 1970s sandwiched between sedimentary rock of the Cretaceous period and the younger rock of the Tertiary period. The debate looked like it could continue indefinitely.

After this Snowbird conference, the second of its kind (*Science*, 20 November 1981, p. 896), the end seems to be in sight. The evidence for an impact continues to mount. The volcanic hypothesis, which has consisted of a hotly contested plausibility argument and claims of inconsistencies in the evidence for an impact, made a poor showing. And the detection of the mineral stishovite, a form of quartz formed only by the extreme pressure of an intense shock, was announced; if confirmed, this evidence would be widely regarded as definitive proof of an impact. Perhaps most encouraging were the frequent agreements between feuding partisans to cooperate finally in sampling, intercalibration, and analysis.

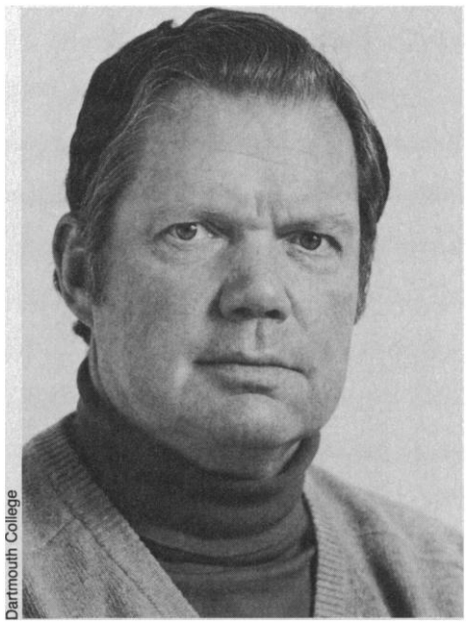
One advantage held by the theory that a large impact killed off more than 70% of the species living at the end of the age of the dinosaurs is the inevitability of such impacts, given the existence of asteroids and comets that cross Earth's orbit. Globally disastrous eruptions remain hypothetical. Eugene Shoemaker of the U.S. Geological Survey (USGS) in Flagstaff told the conference about his latest estimates of the frequency of large impacts based on discoveries of Earth-crossing asteroids and comets. About every 100 million years on average, Shoemaker concludes, an object 10 kilometers in diameter slams into Earth at perhaps 20 kilometers per second or more, releasing 60 million megatons of energy and creating a 150-kilometer-wide crater. That is the size impact thought necessary to explain the chemical composition of the layer at the boundary between the Cretaceous and Tertiary periods. (K-T boundary is used to denote this moment in geological time.)

Bruce Bohor of the USGS in Denver soon followed with a recounting of how the K-T boundary seems to be littered with the debris of such an impact. There are the shocked quartz grains shot through with intersecting lamellae characteristic of the extreme pressure generated by intense shocks. Multiple lamellae have been found only in minerals from known impact sites, nuclear test sites, laboratory shock experiments, and the K-T (*Science*, 25 May 1984, p. 858). And there are spinel crystals, hollow spherules, and vitric clasts unlike anything spewed from volcanoes. All this evidence is consistent with an impact, excludes a volcanic eruption, and is consistent with most of the geochemical evidence, Bohor said.

The volcanologists invited to the conference, who had not as yet been drawn into the volcano versus impact controversy, provided little moral support for the eruption advocates. There have been huge eruptions, the volcanologists noted, far larger than any experienced by humans. About 16 million years ago, eruptions in eastern Oregon and Washington over a period of days spewed forth batches of lava as large as 5,000 cubic kilometers to form lava lakes up to 700 kilometers across. The eruption of Long Valley caldera in California 700,000 years ago dumped 5 centimeters of ash on much of the central United States. And no one can say that even larger eruptions have not occurred.

Even with this daunting record of eruptions, the volcanologists could not offer

*Global Catastrophes in Earth History: An interdisciplinary conference on impacts, volcanism, and mass mortality, held 20 to 23 October at Snowbird, Utah. Sponsored by the Lunar and Planetary Institute and the National Academy of Sciences.



Charles Officer *has been the leading spokesman of those favoring a terrestrial cause of the Cretaceous-Tertiary extinctions, probably a volcanic one.*

concrete evidence of an alternative to a K-T impact. Referring to Bohor's litany of mineralogical evidence, Peter Lipman of the USGS in Denver told the audience that he had been looking at volcanic minerals for 25 years and "we just don't see this kind of thing. I don't see how you can do it with a volcano." On the other hand, "I don't see how impacts could avoid triggering volcanoes" that were poised to erupt. Later in the meeting experts in the dynamics of Earth impacts added the likelihood that deep, hot rock exposed in an impact crater would "erupt," if only for a short while, and the possibility that an impact would release magma confined at the base of the plate.

Bohor's rendition of the evidence prompted one of the longer discussions of the meeting. First to the questioner's microphone was Alan Huffman of Texas A&M University. He works for Neville Carter, the chief shocked mineral expert on the volcano side. Huffman called for a complete, quantitative inventory of all features in minerals that suggest shock. Stishovite, of course, would be a definitive indicator of extreme high pressures and thus an impact, he noted.

The chief spokesman for a purely volcanic event at the K-T, Charles Officer of Dartmouth College, soon came to the head of the line. He wanted to point out that the presence of shocked quartz grains was not as definitive as the impact advocates would like to think. In his now familiar argument, single, nonintersecting sets of lamellae found in volcanic ash demonstrate intense shock, as does shock mosaicism, a dark, patchy structure seen in optical microscopy. The behavior of both types of features at high temperature and their distribution across 4 meters of sediment spanning the K-T at Gubbio, Italy, instead of the few centimeters claimed by impact advocates, argues for a volcanic source, Officer said.

"That's fine," replied Bohor, "but you have nothing at volcanoes that has multiple lamellae. And there is no reason to assume that so-called visible shock mosaicism has anything to do with shock. We need some hard data, Chuck. This is not volcanic."

It is true, Officer conceded, that multiple lamellae have been found at the K-T but not yet in volcanic material. On the other hand, stishovite is found at known impact sites but not at the K-T.

This exchange considerably lengthened the line at the microphone. The large majority of the subsequent comments were pro-impact. Richard Grieve of the Geological Survey of Canada in Ottawa reported that he and his colleagues could not duplicate the laboratory work on the shocking of cold and hot quartz that Officer had cited as support for signs of shock in volcanic ash. Virgil Sharpton of the Lunar and Planetary Institute in Houston had looked at the supposed shock mosaicism in volcanic material and found a chemical zonation across such features. That, he noted, would not be expected from a mechanical process such as shock.

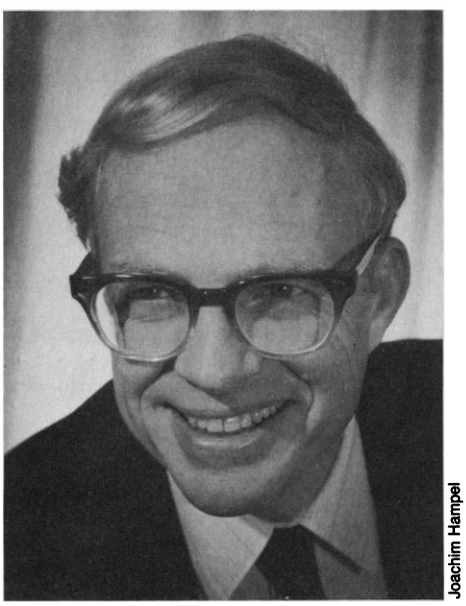
Glen Izett of the USGS in Denver reinforced Lipman's statement. No one at any time in any study of volcanic ash had seen multiple lamellae, he noted. When contamination by surface rock is avoided, he said, no lamellae of any kind are seen in volcanic ash. Shoemaker, up next, agreed with Izett and explained why no one should be surprised that that was the case. Even a violent volcanic eruption is not an explosion and therefore cannot produce the high pressures of a shock, he insisted. An eruption is a decompression, not a detonation, in which everything flows down a pressure gradient, he explained. Any mechanism purporting to create a volcanic, shock-producing explosion is "a mythical beast, a unicorn."

The next day Officer had his chance to present the volcano hypothesis at length. He emphasized that a variety of specialists were finding evidence of extinctions and violent upheavals of Earth over hundreds of thousands of years spanning the K-T. Both the enhanced iridium, which was supposedly deposited within a year or two of the impact, and shocked quartz resembling that found in volcanic ash were found over 4 meters of the Gubbio K-T instead of a few centimeters. The Deccan Traps of India, flood basalts several times more voluminous than those in Oregon and Washington, seem to have formed primarily at or very near the K-T.

Officer made one concession, a new one; he could not exclude the possibility of an impact in western North America. It is generally agreed that the evidence of an impact there is confined to a layer a few centimeters thick. There is even a 35-kilometer-wide crater, the Manson structure in Iowa, that is now dated at 66 plus or minus 1 to 2 million years, right on the K-T.

Once again, Officer drew a big, and largely adversarial, crowd to the questioner's microphone. Among the early questioners was Edward Anders of the University of Chicago. He had a list drawn up for the overhead projector of 18 items he found in a paper in *Science* by Anthony Hallam, who was advocating a gradual, terrestrial cause for the extinctions near the K-T. Each item was color-coded. The eight in red were wrong, according to Anders, the five in blue were probably wrong, and the five in black were true but misinterpreted. After hearing Officer, he said, he could add another half dozen items to the list. Hallam responded that the list had been discussed at an earlier meeting and the result was a draw. Anders begged to differ.

Next up was Frank Asaro of the Lawrence Berkeley Laboratory, who along with colleague Helen Michel has been measuring iridium at the K-T and other boundaries for 10 years. He reported the analysis of a clay layer 1.8 meters below the K-T boundary layer at Gubbio. This clay layer allows a calibration between laboratories because there can be little doubt that everyone is



Walter Alvarez *was a co-originator of the impact hypothesis of the Cretaceous-Tertiary extinctions.*

measuring the same, easily identified layer. According to analyses by James Crocket of McMaster University it contains 2.59 ± 1.03 parts per billion of iridium, which rivals the 9 parts per billion found at the K-T. Officer cites such high iridium away from the boundary as evidence of prolonged, probably volcanic events across the K-T. Asaro and Michel found only 0.198 ± 0.065 parts per billion, the background concentration there. The analysis for iridium is infamous for its sensitivity to contamination, all verified errors in the K-T debate having been on the high side.

Asaro suggested that the Berkeley group and the McMaster group, which has included Officer, should lay the matter to rest by jointly sampling and analyzing samples. Officer agreed. The audience signaled its approval as well.

Geologist Walter Alvarez of the University of California at Berkeley spoke next to emphasize the point made by Asaro. Asaro, Michel, Alvarez, and his late father Luis Alvarez originally proposed the K-T impact after finding elevated iridium at the K-T at Gubbio in 1978. The two groups differ on more than iridium, Alvarez noted. He and his colleagues cannot find shocked minerals spread across 4 meters at Gubbio either. "We do not find that when we use carefully cleaned samples," he said.

The specter of contamination has haunted Gubbio before, Alvarez noted. In one case a published paper redated the sediments as 15 million years old rather than their true age of 66 million years because young foram microfossils used as time markers had fallen onto the exposed rock face of the K-T. In another case, tiny glassy spherules attributed to the K-T impact by others were collected from well above and below the Gubbio K-T, just like the iridium and shocked minerals were claimed to be. Alvarez did not mention it, but the broadly dispersed spherules formed another part of the gradualists' argument as put forth in 1985 by Officer and Charles Drake, a colleague of Officer's at Dartmouth. The supposed mineral spherules turned out to be insect eggs. "We need to get together," Alvarez noted, adding that Drake is enthusiastic about a cooperative effort. "It will be resolved. I'm delighted we're going to have a joint sampling trip and a blind analysis of split samples. This is the way we should do our science."

On the third and last day of the meeting, Alvarez had a chance in his own talk to expand on the quality control question. The sedimentary record, he reiterated, is subtle and easily contaminated. Among other steps, use of only the best sites would help, he noted. He contrasted the K-T boundary as exposed at Caravaca, Spain, where the event is confined to 1 to 2 millimeters of sediment, and Deep Sea Drilling Project site 465A, where the act of drilling squirted a meter of Tertiary sediment downward in the core into the Cretaceous and vice versa. This K-T core had been cited by Officer and Drake as potential evidence of a prolonged event at the boundary.

Alvarez had some suggestions as to how the impasse might be resolved to everyone's satisfaction. His prescription included statistical testing of analytical results, blind analyses, interlaboratory calibrations, searches for new boundary exposures, and more thorough sampling of the boundary.

Unmentioned by Alvarez was the possibility of applying new types of analyses. In the question period, John McHone of Arizona State University announced the results of a new test to distinguish between an eruption and an impact. He and his colleagues had processed 8 kilograms of K-T boundary rock from Colorado until it was reduced to 8 milligrams of concentrated sample that could be placed in a nuclear magnetic resonance spectrometer. "I clearly detected the presence of stishovite, the mineral that almost everyone agrees is definitive for high pressures" typical of an impact. "I don't see how a volcano could do it.

Impact may be a more pervasive factor in extinction than has been assumed.

If an asteroid or comet impact caused the mass extinction at the K-T boundary, as much of the data presented at Snowbird suggests, what role is left for the conventional agents of evolution, such as Darwinian competition and natural selection driven by changes in climate and sea level? David Raup of the University of Chicago suggested that the inevitable rain of objects onto Earth may well leave little room for conventional mechanisms to shape evolution in the long run.

Raup ran a Monte Carlo model of the effectiveness of the flux of impactors predicted by astronomers in killing off genera of marine animals during the past 600 million years. The appearance of the resulting plot of percent genera killed with time, once events are grouped as they are in the geologic record, bears a striking resemblance to the actual record—a noisy background of extinction, a number of moderate events, and a few in which 50% or more of the genera were killed.

Are the conventional, gradual mechanisms needed? They do work at the local level, Raup said, but "I submit that these mechanisms have never been clearly tested" on a continental scale. For example, the past 2 million years, a time called the Pleistocene epoch during which there was a procession of ice ages and widely varying sea level, produced virtually no extinctions that would have shown up in the 600 million record that he used. "We should be concerned that the Pleistocene does not hold up as a major extinction event," he said. "We should take a hard-nosed look at the conventional mechanisms. Large body impact may be a more pervasive factor in extinction than has been assumed heretofore."

All this tickled Stephen Jay Gould no end. The Harvard University paleontologist delivered the closing address in which he pointed out that the meeting's theme of catastrophism fits nicely into his view of extinctions and evolution. For his own reasons, Gould suspects that Darwinian evolution, involving biological competition for niches that are altered from time to time by moderate physical changes on Earth's surface, does not have the opportunity to dominate evolution.

Catastrophic extinctions caused by impacts would change the rules governing who is most fit, who becomes extinct, and who survives. "If much of the patterning of life's history is not set by Darwin's slow biotic mechanisms, then I think Darwin is in trouble. Is catastrophic mass extinction a major agent of patterning?" If so, "impacts are a quirky aspect" of the process.

In a quirky world, humans' ancestors, the mammals, might not have survived the K-T boundary because of some commendable adaptation that we still carry. Instead, their saving grace may have been some attribute, such as their small size, that only became a decisive advantage during the moment of the catastrophe. "The history of life is enormously more quirky than we imagined," said Gould. "I'm not saying that it's random. It's explainable after the fact, but there's no predictability." An explosion of diversity would eventually be followed by a winnowing, perhaps induced by a global paroxysm. "It is not easy to deal with a phenomenon orders of magnitude beyond experience. It would be a lot easier with gradualism. Although it's difficult, catastrophism may be the way it happened."

■ RICHARD A. KERR

ADDITIONAL READING

A. Alvarez, "Toward a theory of impact crises," *Eos* **67**, 649 (1986).

A. Hallam, "End-Cretaceous mass extinction event: Argument for terrestrial causation," *Science* **238**, 1237 (1987).