Periodic Impacts and Extinctions Reported

In a potentially historic workshop, researchers sought a trigger for comet showers that might ultimately drive evolution and even climate change

The proposal that a huge asteroid hit the earth 65 million years ago and wiped out all manner of plants and animals, perhaps including the dinosaurs, was bad enough. Catastrophism had been out of vogue for 100 years. Now that geologists and paleontologists are becoming more accommodating to the occasional catastrophe, some researchers are proposing that impacts come in swarms that return about every 28 million years, indiscriminately pushing species to extinction and driving the evolution of the earth's climate in new directions.

According to some theories, an unseen companion of the sun may be behind it all. These and other provocative proposals were the subject of a hurriedly arranged workshop in Berkeley at the beginning of March.* From the excited gathering of about 30 invited participants emerged, among other things, tantalizing correlations between periodic cratering, climate change, and mass extinctions through the past 250 million years.

The idea that a swarm of comets pelts the earth once in a great while is not new, but has not until now received much attention. Jack Hills of Los Alamos National Laboratory suggested in a 1981 paper (*1*) that the exceptionally close passage of another star by the sun would send a billion comets falling into the inner solar system toward the earth. That would happen every 500 million years on average, or nine times in the history of the earth. It would not happen more often because, as Hills suggested and others increasingly accept, most of the comets circling unseen far beyond the planets are too close to and thus too tightly bound by the sun to be gravitationally diverted by most passing stars.

The traditional view of the comets that are now seen blazing through the inner solar system is that they come from a sparse halo of icy, necessarily inactive comets more than 20,000 times farther from the sun than the earth [a distance of 20,000 astronomical units (AU)]. These are so loosely held by the sun that many of the stars randomly passing by can gravitationally divert these comets into the inner solar system. An emerging view adds that 10 or 100 times more comets reside in a compact reservoir inside 20,000 AU where they are too close to the sun to be perturbed by the typical passing star. Once in 500 million years, however, a star might pass as close as 3,000 AU from the sun and trigger a comet shower 700,000 years long. Instead of just the five new comets appearing in the inner solar system each year from the outer halo, 5,000 to 10,000 from the inner reservoir would plummet toward the sun annually, according to Hills' calculations.

Hills duly pointed out that the earth could not escape being hit by 10 to 200 of these comets during 700,000 years—that is greater than 1,000 times more often than normal. He also found it "tempting to join the 'me too' parade and suggest that this bombardment could have led to the extinction of the dinosaurs" in accordance with the impact extinction theory proposed in 1980 by Nobel laureate Luis Alvarez of Lawrence Berkeley Laboratory (LBL), his son Walter Alvarez of the University of California (UC) at Berkeley, and Frank Asaro and Helen Michel of LBL.

All species may be equally liable to extinction by a single external cause, presumably an extraterrestrial one.

The proposed comet swarms had little effect on anyone's thinking until David Raup and John Sepkoski of the University of Chicago began talking about extinctions that seem to have been on a regular 26-million-year schedule (*Science*, 2 September 1983, p. 935) (*2*). Sepkoski had been amassing a record of the appearance and extinction of 3500 families of marine animals. When he and Raup plotted rates of extinction against time, they saw three or four episodes of mass extinction during the past 250 million years. However, when they weeded out all but the 567 most well-understood extinct families and calculated percentage of extinctions, much of the noise in the record disappeared and 12 peaks stood out.

With an improved extinction record in hand, Raup and Sepkoski looked for any regularities by applying Fourier analysis, a technique that attempts to approximate a time series like the extinction record by a combination of sine and cosine curves. They found a periodicity in the neighborhood of 30 million years but did not trust it because the Fourier analysis could have created it from the irregular length of the geologic time spans by which the extinction data were arranged.

To verify the reality of the periodicity, they used a "bootstrap" method to determine the best fit of regular cycles to the extinction record and to 8000 randomized versions of the same record. The cycle that had the best fit to the real data had a period of 26 million years; no cycle fit the random simulations as well, indicating a confidence level of 99.7 percent. With a few exceptions, major extinctions seemed to fit the 26-million-year cycle. If this periodicity in the extinction records is real, Raup and Sepkoski noted, the implications for "evolutionary biology are profound." All species may be equally liable to extinction by a single external cause, they concluded. For lack of obvious terrestrial possibilities, they suggested some kind of extraterrestrial cause.

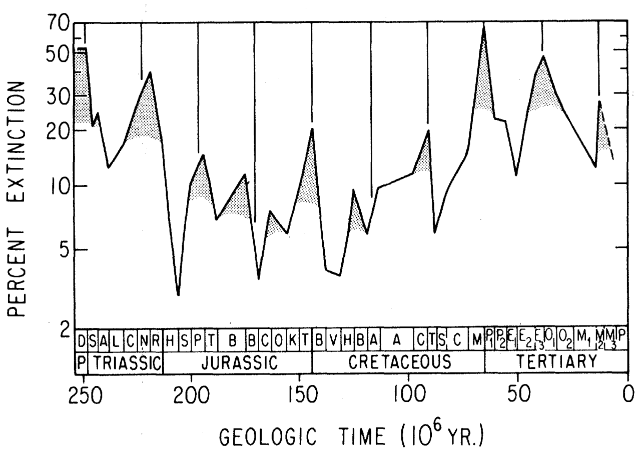
Hills never heard about Raup and Sepkoski's periodic extinctions, but plenty of other researchers did. Through word of mouth, preprints, and particularly news stories in *Science* and *Science News* last September; researchers who for one reason or another think more about outer space than the fossil record heard about the proposed 26-million-year periodicity. The rush was on. Within an hour after Luis Alvarez showed astronomer Richard Muller of LBL and UC Berkeley, his ex-student, a preprint of the Raup and Sepkoski paper, Muller concluded that an unseen companion circling the sun once every 26 million years could be responsible.

How a companion star could cause extinctions Muller did not know until he talked to fellow astronomers Marc Davis of UC Berkeley and Piet Hut of the

*A workshop on multiple comet impacts and their effect on evolution held 3–4 March at the Lawrence Berkeley Laboratory was organized by Luis Alvarez, Frank Asaro, Helen Michel, and David Raup.

Institute for Advanced Study in Princeton. If Hills' random passing star was replaced by the regular close approach of a companion circling the sun in a highly elongated orbit, the companion could periodically send a shower of comets, a billion strong, toward the earth. Unaware of what was going on in Berkeley, Daniel Whitmire of the University of Southwestern Louisiana and Albert Jackson of Computer Sciences Corporation in Houston were collaborating on their own version of the companion.

The companions proposed by the two groups differ in detail; both companions are diminutive, but Whitmire and Jackson's is smaller and is in a more elongated orbit. Such a companion would have at most a tenth the mass of the sun, making it a white dwarf star that has burned all of its nuclear fuel. If it were as small as a few thousandths of the solar mass, it would be a giant Jovian-style planet whose nuclear fires never ignited.



A record of extinctions

The proposed 26-million-year cycle of extinction (vertical lines) is superimposed on the record of extinctions as analyzed by Raup and Sepkoski. The relative heights of the younger peaks are exaggerated by this analysis. [Reproduced from (2)]

A companion from the smaller end of the range would have to penetrate the inner comet reservoir inside 20,000 AU to cause a shower; a larger one need only approach to within 30,000 AU in the outer cloud. Either would roam outward more than 150,000 AU or 2.5 light-years. That would be more than halfway to the nearest star.

The highly elongated orbit of any companion presents a problem—it probably is not stable. Almost half a billion stars passing nearby would have tugged on a companion since the origin of the solar system 4.5 billion years ago.

Hut presented the results of mathematical simulations of the effects of star passages, beginning in each case with the hypothesized present orbit. In no simulated case did a companion survive as long as 4.5 billion years, flying off instead after at most a few billion years or as early as 100,000 years. In only half the cases could a companion maintain under the continual jiggling by passing stars an orbit whose period varied by no more than 10 percent over 250 million years. To make matters worse, an infrequent encounter with one of the galaxy's giant clouds of gas might also strip the companion from the sun. The suggestion of a companion in the necessary orbit is "viable, certainly possible," concluded Hut, "but it's not every wide binary that can do this." To have survived this long, he noted, such a companion must have formed in a tighter, more stable orbit about the sun and only later moved outward to its present orbit.

This is where Eugene Shoemaker of the U.S. Geological Survey (USGS) began to have some problems. On the basis of simulations and some back-of-the-envelope calculations, Shoemaker argued with Muller and Hut that a companion might be physically capable of creating periodic comet showers, but it is highly improbable that it would do so. The problem is placing the companion in a stable orbit that will produce comet showers distinctly more intense than the background flux of comets produced by passing stars while not wiping out the comet cloud during the hundreds of its orbits completed since the formation of the solar system.

Shoemaker's best estimate is that there is only about a 0.1 to 1.0 percent probability that a companion would do all that. Muller and Hut were not happy with Shoemaker's quick and dirty calculations, but they all agree on what calculations must be done. "When we finish, I think we're going to be very close" in our results, Shoemaker said.

Some theorists avoided any problems with the stability of a wide-ranging companion by attributing the long-period variations of the extinction record to the solar system's passage through the midplane of the disk of the galaxy. The sun bobs up or down through the galactic plane about every 30 million years. Michael Rampino and Richard Stothers of Goddard Institute for Space Studies thought first of this ready-made periodicity and suggested that the most likely way that a galactic plane crossing could lead to extinctions was through encounters with intermediate-size galactic clouds, which are bunched near the galactic plane. The gravitational pull of such a large though dispersed mass could also create comet showers.

The Rampino and Stothers preprint has not had wide circulation, but one problem noted with their approach is that the extinctions and the predicted plane crossings do not coincide well enough. Rampino replies that rather than a failure of their hypothesis, the lack of perfect coherence between prediction and the fossil record is an expected attribute of their mechanism. The scatter of clouds around the galactic plane should create scatter in the correlation between the extinction record and plane crossings, as observed.

A glaring example of this kind of scatter is the solar system's present position at the galactic plane while we are at the midpoint of the extinction cycle (the last event having been 13 million years ago). Richard Schwartz and Philip James of the University of Missouri avoid this potential hitch by suggesting that extinctions occur when the sun is at its extreme positions above and below the galactic plane. There, beyond much of the shielding gas and dust of the galaxy, increased exposure to soft x-rays and hard ultraviolet radiation might alter the atmosphere in a way that ultimately might change climate, Schwartz suggests.

The periodic impact hypothesis of extinction would not be receiving so much attention had it not been reported that ancient impact craters on the earth have tended to fall at the times of the periodic extinctions. Three independent analyses have now been made of the cratering record. Each used different criteria to select the most representative craters from the list of 88 probable craters.

Walter Alvarez and Muller selected craters having ages between 5 and 250 million years old, dating uncertainties of 20 million years or less, and diameters greater than 10 kilometers. Fourier analysis of their 13 craters indicated a period of 28.4 million years, with a confidence level of about 99 percent. Applying less stringent selection criteria, Rampino and Stothers found a 31-million-year periodicity in their 41-crater record using a different statistical technique. Subsequently, as reported at the workshop, Raup applied the same "bootstrap" method as used in the extinction study to 19 selected craters. The resulting period was 28.5 million years with a confidence level of 99.8 percent.

Perhaps more impressive than the apparent high confidence levels and near identity of calculated periods is the coincidence of the reported times of comet showers and mass extinctions. Alvarez and Muller find the most recent comet shower to have been 13 ± 2 million years ago, the same age reported for the most recent extinction event. The next three or four periodic extinction events fall neatly within the age ranges of the cratering episodes, in part because their permissible age ranges expand with the accumulation of the million-year uncertainty in the cratering periodicity. Errors in the dating of mass extinctions also increase in the more distant past, allowing a doubling up of two extinctions at the seventh and ninth cratering cycles.

Some researchers are not convinced by the statistical arguments for periodicity. Richard Grieve of Brown University, who originally compiled the terrestrial cratering record, is not bothered by the suggestion of spikes of cratering in the record, but periodicity is another matter. "They've done it the best way they can," he says of the analyses, but "it's just not a data set that's amenable to time-series analysis." The problem, he says, is that any million-year date without a crater in the selected record is assumed to lack a crater in reality, and this creates an artificial and misleading background of zero events per million years. Among other problems, Grieve notes that chemical analyses of some of the selected craters indicate an asteroid as the impactor rather than a comet.

One of the few cautionary notes of the workshop was sounded by David Jablonski of the University of Arizona when he noted, on the basis of an admittedly hasty compilation, a curious coincidence between the ages of craters and apparent decreases in sea level. Could the cratering record be biased by a periodic increase in the area of the impactor's target—the continents—due to a fall in sea level? No one had a ready answer.

The suggestion of periodic extinctions by comet showers is stimulating as much constructive hypothesis testing as did the original claim for a devastating impact 65 million years ago, as well it should. The implications are profound not only for the driving forces behind evolution but also for those behind climate change; if periodic comet showers instead of climate change are the ultimate cause of mass extinctions, then presumably comet showers also cause permanent changes in climate.

Tantalizing evidence of the expected association between multiple impacts, climate change, and extinctions was presented at the workshop. Erle Kauffman of the University of Colorado has found apparent climate oscillations in the half million years immediately preceding the extinctions of 91 million years ago. No signs of an impact have yet been found there, but similar oscillations seem to have preceded other mass extinctions, including those now associated at least in part with the impact 65 million years ago. Gerta Keller of the USGS in Menlo Park reported evidence (*3*) of debris from several impacts clustered around 38 million years ago, about the time of major climate changes and extinctions. Expanding on such studies, as well as searches of the sky for the companion, will be the next steps in testing the new hypotheses.—**RICHARD A. KERR**

References

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The Necessity of Knowledge

The essence of intelligence seems to be less a matter of reasoning ability than of knowing a lot about the world

The field of artificial intelligence, or AI, is split into two camps. The "engineers" are trying to get their programs to do smart things, by whatever means they can. The "scientists," a much smaller group, are after a general theory of intelligence, both human and machine.

Either way it is a tough job. Even the enthusiasts have to admit that AI's achievements to date are at best embryonic. The utilitarian approach has produced some reasonably effective software, and in the case of the so-called expert systems that software has begun to be successful in the marketplace (*Science*, 24 February, p. 802). But the main thing that AI researchers have gained on the theoretical front is a certain humility, an appreciation of how awesomely complex the most ordinary human act can be—and of just how much a computer (or a human) has to *know* before it can do much of anything.

On the other hand, it is the computer that gives AI its promise. The fundamental assumption of AI is that the mind can be modeled as a processor of symbols—in effect, as a computer program. Cognition is considered to be a high-level process, which means that it can no more be understood in terms of the firing of individual neurons than a computer program can be understood in terms of the 1's and 0's flitting through an individual memory register.

Given that assumption, the fundamental methodology of AI is strikingly like that of mathematical physics: first turn a set of abstract speculations about the mind into a concrete computer program (write down the equations), and then make that program perform (solve the equations). If it works, then maybe the model was a good one to begin with; if it does not, then maybe a study of how the model breaks down can suggest a better one. At the very least this process enforces a certain clarity and precision, and weeds out ideas that are fuzzy, or incomplete, or wrong.

Historically, AI was a product of the post–World War II ferment in information theory, control theory, and cybernetics; people were writing AI-like programs almost as soon as computers were equipped with enough memory (about 4 kilobytes) to handle them. But it really only emerged as a well-defined field in the mid-1950's. In fact the name "artificial intelligence" itself was only invented in 1956, when John McCarthy, now at Stanford University, used it to describe a summer workshop he was organizing at Dartmouth College.

Those were the days when everything seemed possible. One of the brightest dreams was the creation of a program that would mimic the full range of human problem-solving abilities, from getting