Extinctions and the History of Life

Now that, for many at least, asteroid impact has been accepted as a causative agent in mass extinction, attention turns to the wider view

"It is a great philosophical breakthrough for geologists to accept catastrophe as a normal part of Earth history." This comment, made by Erle Kauffman at a meeting on the dynamics of extinction held recently at Northern Arizona University, Flagstaff,* identifies a currently important, perhaps revolutionary, shift in collective professional perspectives among paleontologists as well as geologists. "We have to accept asteroid impacts as part of the uniformitarian process," agrees Jerre Lipps, of the University of California, Davis.

Like most meetings on extinction these days—and there have been many—the Flagstaff gathering repeatedly saw discussion return to the asteroid-impact hypothesis as a cause of the late Cretaceous extinction, which, among many biological events of greater significance, included the final demise of the dinosaurs. In contrast with the narrow focus of most meetings, however, this one sought to assess mass extinction as part of the pattern of life throughout the Phanerozoic, the past 600 million years.

How should one try to identify mass extinctions in the fossil record? Is there any periodic pattern to mass extinction throughout the history of life? And how does each event compare with the others? These were the kind of general, and deceptively difficult, issues that were grappled with at Flagstaff. But perhaps the most persistent theme concerned the nature of mass extinction relative to the constant tick of background extinction. Do the large events inflict the same kind of biological effect as obtains in quieter times but on a grander scale? Or are these episodes so extraordinary that, as David Jablonski, of the University of Arizona, Tucson, puts it, "all biological bets are off?"

Neither Kauffman nor Lipps meant to imply by their statements that they and their colleagues had discarded the ruling concepts of gradualism in favor of the notion of rocks periodically falling out of the sky with devastating impact as the principal explication of biotic history. Indeed, if anything, the meeting was biased in favor of those who lean toward earthbound, as against extraterrestrial, agents as a cause of, specifically, the late Cretaceous extinction. No, the new catastrophism, if such an emotive phrase can be permitted, for many would disavow the designation, merely allows for asteroid impact as one of many agents that from time to time profoundly perturb global conditions important to life, including atmospheric and oceanic circulation, temperature gradient, and sea level. The resulting biotic devastations might well transcend organisms' relative adaptiveness or fitness and so cause extinctions as much through bad luck as bad genes. Each mass extinction in a sense resets the evolutionary clock and so makes the history of life strikingly spasmodic and governed by a greater element of chance than is palatable in strict uniformitarianism.

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It was, however, the asteroid hypothesis that brought the participants to Flagstaff, albeit indirectly. "Until very recently the study of mass extinctions was just a cottage industry," says Jablonski. "But the interest associated with the asteroid hypothesis has really changed the science. That testable model has forced everyone to improve their own approach to alternatives. There is now a great deal of attention to large-scale patterns."

One of the problems of paleontology is the resolution with which such patterns can be discerned. The notorious paucity of the fossil record combines with a greatly varying sedimentation rate to make time resolution of faunal changes little short of a nightmare. Add to this the gargantuan task of compiling all available origination and extinction data on the 200,000 known marine fossil species, not to mention the need to untangle the inevitable vagaries and inconsistencies of such records, and the prospects for early solution to the challenge look slim. John Sepkoski, who undoubtedly has the most complete data set on the marine fossil record at the family level, is embarking on the task at an intermediate taxonic level, genera. "This could take 5 to 10 years," he says.

Meanwhile, Sepkoski, who works at the University of Chicago, has utilized the family level data to plot changes in diversity through time and therefore to identify periods of extinction throughout the Phanerozoic, a project he undertook with David Raup, also at Chicago. The resultant plot, which was on show during virtually every presentation at Flagstaff, is described by Jablonski as "a tremendous quantitative advance in the study of mass extinction."

Sepkoski and Raup see a background extinction rate, which declines steadily through time, of three to five families per million years, or 180 to 300 species. This "normal" extinction is punctuated by five notable mass extinctions with a rate as high as almost 20 families, or 1200 species, per million years. In addition to the big five there are an additional five "lesser" mass extinction, all of which occurred since the biggest event of them all, the Permian extinction, 240 million years ago, in which upwards of 95 percent of marine species disappeared.

Now, a number of difficulties arise through charting the appearance and disappearance of families through time, of which Sepkoski and Raup are only too keenly aware. For a start, the time scale is calibrated in somewhat arbitrary units known as stages, which usually represent just over 7 million years. The plotting cannot therefore discriminate between events that occur evenly over that period or are instantaneous at some point within it. Secondly, recording the presence or absence of a family can be extremely insensitive to what might be major changes in the group: a family of, say, 60 species could be devastated to one survivor, and yet no record of change would be made. (It could be called the Cheshire cat effect.) And, in any case, the family is a somewhat artificial taxonomic abstraction: "A family is

*Dynamics of Extinction, Northern Arizona University, 10 to 12 August 1983.

a mysterious unit to an ecologist," says Daniel Simberloff, of Florida State University.

Digby McLaren, of the Geological Survey of Canada, has been vocal in calling for more attention to species-level changes, and indeed to changes in biomass, as a more realistic indicator of extinction. McLaren does not belittle the heroic efforts of Sepkoski and Raup but believes that the relative insensitivity of their current approach has failed to detect all the mass extinction events that might have occurred. Sepkoski agrees.

In addition to a true quantitative indication of the existence of mass extinctions, which they expected, Sepkoski and Raup have in recent months seen in their data a strong suggestion of periodicity of extinctions, which they did not. The two Chicago workers have tried very hard to see if the extinction periodicity they detect, which has a 26-million year cycle through the past 240 million years, is some kind of statistical artefact, an all too common snare for the unwary in this type of data plotting. So far the signal has stubbornly refused to be statistically massaged out of the data. "Although it causes me some considerable philosophical anguish," says Sepkoski, "the periodic signal does begin to look real."

A periodic cycle of extinctions would, of course, imply a common cause for each event. "I'm entirely stuck for a mechanism for causing such a period, but I suspect that the forcing agent would not be earthbound." Enter asteroids and other extraterrestrial influences.

In a presentation that gave many skeptical biologists and paleontologists reason to place greater weight on the reality of asteroid impacts as bioperturbation events, Eugene Shoemaker, of the U.S. Geological Survey, Flagstaff, told the conference that the earth could expect to incur a significant impact on a 50-million year cycle. Smaller, less devastating, impacts would occur more frequently.

The gap between the Shoemaker and Sepkoski cycles is large, but, as the latter noted at the end of the meeting, one is just twice the length of the other. "It is possible," said Sepkoski, "that our data in fact contain a 52-million year cycle superimposed on which are aperiodic events that cluster between the major events, which give the appearance of a 26-million year cycle." He would return to Chicago to test the idea, he promised. So far, in the week following the conference, Sepkoski and Raup have been unable to wrest a 50-million year cycle from the data, though it cannot yet be fully ruled out. For the moment at least, the 26-million year period remains—a mystery.

McLaren has long been receptive to the idea of large rocks falling from the sky as possibly being influential in extinction events. Nevertheless, he spoke for many at Flagstaff when he said, "From many lines of evidence we must now accept that large-body impacts have occurred . . . and attempts must be made to assess the relative importance of such contributions."

While biological effects of, say, marine regressions or global temperature changes should be gradual, the impact of a collision with an asteroid might be expected to be more short term, depending on the medium of perturbation induced. McLaren repeatedly insisted that ultimate and immediate causes of extinction should be clearly separated. For instance, shifts in atmospheric and oceanic circulation might inflict mass extinction on a global scale over a very long period. But such an environmental change might be the result of either plate tectonics (a slow process itself) or conceivably of asteroid impact (an instantaneous process). So, although there would undoubtedly be local devastation from an impact, radiating many hundreds or even thousands of miles from an epicenter, the more significant biological effects might result from long-term climatic perturbations. An iridium anomaly at a sedimentary boundary, which currently is taken to be the signature of a collision with an extraterrestrial body, would therefore not inevitably be associated with extremely rapid extinction on a global scale.

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Indeed, both Lipps and Jablonski expressed doubt that the spectrum of biological damage seen at the late Cretaceous extinction boundary could properly be related to the dramatic physical changes—such as 3 months of darkness—that asteroid-impact proponents have suggested. "The biological effects are just too mild for this degree of perturbation," says Jablonski. Lipps likes to entertain the notion that asteroid impact might induce an El Niño–like situation in which, among other things, biologically productive oceanic circulation is interrupted. "This could bring about the results we see in both the marine and terrestrial record," he says. "I like the idea," assents Jablonski. There was no one present qualified to comment on the proposal.

Because of the recent intense interest in the asteroid hypothesis for the late Cretaceous extinction, this geological boundary is now probably the most thoroughly scrutinized few meters of sediment throughout the Phanerozic record, both geochemically and paleontologically. Do the fauna disappear rapidly at the boundary or diminish slowly towards it, the paleontologists wish to know. In trying to answer this question it has become painfully clear that apart from the marine microfossil record the available data are just too ambiguous to provide immediate solution.

Although the oceanic microplankton do appear to have suffered catastrophically at the boundary, the victims, perhaps of months of darkness or disturbed oceanic circulation, depending upon one's taste, other more prominent fauna, such as the dinosaurs and the ammonites seem not only to have been in decline before the iridium-containing boundary but also to have been represented by just a handful of species at this terminal event. In other words, the extinction of these giant reptiles, the ammonites, and other organisms in similar precarious states might have been much less dramatic than it appears, an illusion of the Cheshire cat effect.

Kauffman, who works at the University of Colorado, has compared some of the geochemical clues to climatic and oceanic conditions at the late Cretaceous and an earlier (late Cenomanian) extinction. In many ways the background to the two events differ sharply: the late Cretaceous was a time of extreme oceanic regression, inequable climate and turbulent volcanic and mountain-building activity; sea levels were at a peak of transgression at the Cenomanian, climates were equable and geology was quiescent. A major difference in the extinction profiles was that although the generalist, geographically widespread species that represent the remnants of many impoverished families survived at the Cenomanian event, as is the pattern for most mass extinctions, at the late Cretaceous they were largely wiped out.

Kauffman said that the approach to both extinctions was marked by increasing fluctuations in ocean oxygenation and in temperature gradients, vertically through the sea column and latitudinally from equator to poles. These fluctuations, which may be related to changes in the earth's orbit around the sun, became extremely erratic at the boundaries and led to severe anoxia of the oceans and reduced temperature gradients. The biological effects of these extreme changes in terms of extinction profile might depend, says Kauffman, on how stressed the biota is from other environmental conditions, such as sea-level shifts. The same might be said for the effects of asteroid impact.

Comparison of all the mass extinctions is clearly a good way to look for patterns of causality, if such exist. Jablonski has done this and concludes that "marine regression is the most impressive common denominator." There are, of course, extinction events that coincide with transgression, not regression; and some regressions appear to leave the biota unscathed. Some of these differences might be accounted for by differences in the starting point of the regression, he suggests. Nevertheless, the pattern is clearly not simple.

One very consistent pattern of mass extinctions, however, is that although each event typically affects different suites of organisms, tropical biotas are nearly always hardest hit, for which there might be several explanations. For one thing, there is always a species diversity gradient from high in the tropics to low in temperate regions, and so there could be a statistical element in the bias toward tropical extinctions. But there are real biological properties that might bear on this too.

For instance, some clades, that is evolutionarily related groups of species, contain many species while others are species-poor. It often happens that species-rich clades have a high rate of extinction, which is matched by a high rate of speciation. In species-poor clades low extinction rates are paired with low speciation rates. Jablonski has shown that during "normal" times of background extinction there is no extinction bias towards either type of clade. During mass extinctions, however, species-rich clades are differentially affected: they suffer more, as might be predicted. Survivors tend to be generalist organisms that are not geographically provincial. (Provinciality turns out to be a very important determinant of vulnerability to extinction.)

As the tropics have a disproportionately high number of species-rich, geographically provincial clades, it is not surprising that this area of the world suffers disproportionately during mass extinctions. These, and other data, lead Jablonski to conclude that "macroevolutionary processes may be qualitatively different during times of background extinction and times of mass extinction."

The study of mass extinction has traditionally focused on the victims of the events. There was at the Flagstaff meeting, however, a strong undercurrent of feeling that more attention to the nature of survivors would provide keen insights into the larger patterns of extinctions and the overall history of life. Geerat Vermeij, of the University of Maryland, is beginning to probe this topic by looking at refuges to which certain species become restricted during mass extinctions. And in the ecological realm it would be extremely valuable to know how resilient various species are to extinction when faced with environmental perturbations of various magnitudes.

Vermeij was not being especially humble when he said, "I feel profoundly ignorant about the nature of extinction." He had articulated what many had felt. The Flagstaff meeting illuminated this large and supremely important subject by showing how very little is known in the face of how very much there is to be known.—ROGER LEWIN

A Visible Free Electron Laser in France

A string of firsts for an Orsay-Stanford collaboration: the first free electron laser in the visible, in a storage ring, and in Europe

A French-American collaboration working at the Laboratory for the Utilization of Electromagnetic Radiation (LURE) of the University of Paris–South in Orsay has reported the successful operation of a free electron laser that emits light in the red-orange region of the visible electromagnetic spectrum. The demonstration is the first of a number that are expected to roll in over the next several months as several second-generation free electron laser projects begin to bear fruit. "These are very exciting times for free electron lasers," enthuses George Neil of TRW, Inc., who heads one of these efforts.

Free electron lasers combine the tunability associated with synchrotron radiation with the high brightness and coherence of conventional lasers and thus constitute an unparalleled tool for spectroscopic and structural investigations of all manner of samples. At the same time, free electron lasers offer the potential for exceptionally high efficiencies for the conversion of electrical to optical energy. This makes them candidates for the huge monsters that would be needed for commercial and defense applications.

In the commercial sphere only infrared carbon dioxide lasers are efficient enough to make them cost-effective for industrial materials processing, such as welding and cutting of metals. And, except for specialized processes like enrichment of uranium-235, no laser is currently a sufficiently inexpensive light source for laser-induced photochemistry.

On the defense side, applications are by nature more speculative, but high-power, short-wavelength lasers are much discussed for missile defense. Free electron lasers have also been mentioned as possible drivers for laser fusion, which can be used for both civilian energy production and nuclear weapons simulation. Most of the free electron laser research in the United States is sponsored by the Department of Defense, which has cautioned some of its contractors not to discuss research results without prior clearance.

Free electron lasers are so named because the electrons that generate the laser light are not bound to atoms in molecules or solids, as is customary. Instead, they are "free" particles in a high-energy, accelerated beam. When the beam passes through an array of magnets (an undulator) that forces it into a sinusoidal trajectory, it emits light. The principle is the same as that which causes synchrotron radiation in circular electron accelerators.

The wavelength of the light emitted is determined by the energy of the electron beam, the spacing between the magnets in the undulator array, and the strength of the magnetic field, rather than by the quantized energy levels of atoms, molecules, and solids. Hence, free electron