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Sex, Drugs, Disasters, and the Extinction of Dinosaurs

Science, in its most fundamental definition, is a fruitful mode of inquiry, not a list of enticing conclusions. The conclusions are the consequence, not the essence. My greatest unhappiness with most popular presentations of science concerns their failure to separate fascinating claims from the methods that scientists use to establish the facts of nature. Journalists, and the public, thrive on controversial and stunning statements. But science is, basically, a way of knowing—in P. B. Medawar's apt words, "the art of the soluble." If the growing corps of popular science writers would focus on *how* scientists develop and defend those fascinating claims, they would make their greatest possible contribution to public understanding.

Consider three ideas, proposed in perfect seriousness to account for that greatest of all titillating puzzles—the extinction of dinosaurs. These three notions invoke the primally fascinating themes of our culture—sex, drugs, and violence—and I want to show why two of them rank as silly speculation, and why the other represents science at its grandest and most useful.

Science works with testable hypotheses. If, after much compilation and scrutiny of data, new information continues to affirm a hypothesis, we may accept it provisionally and gain confidence as further evidence mounts. We can never be completely sure that a hypothesis is right, though we may be able to show with confidence that it is wrong. The best scientific hypotheses are also generous and expansive: they suggest extensions and implications that enlighten related, and even far distant, subjects. Simply consider how the idea of evolution has influenced virtually every intellectual field.

Useless speculation, on the other hand, is restrictive. It generates no testable hypothesis, proposes no way to obtain potentially refuting evidence. Please note that I am not speaking of truth or falsity. The speculation may well be true; still, if it provides, in principle, no material for affirmation or rejection, we can make nothing of it. It must simply stand forever as an intriguing idea. Useless speculation turns in on itself and leads nowhere; good science reaches out. But, enough preaching. Let's move on to dinosaurs, and the three proposed causes of their extinction.

How could we possibly decide whether the hypothesis of testicular frying is right or wrong? At what temperatures did their testicles cease to function? We would have to know things that the fossil record cannot provide

1. Sex: Testes function only in a narrow range of temperature (those of mammals hang externally in a scrotal sac because they need to be cooler than the body). A worldwide rise in temperature at the close of the Cretaceous period caused the testes of dinosaurs to stop functioning and led to their extinction by sterilization of males.

2. Drugs: Angiosperms (flowering plants) first evolved toward the end of the dinosaurs' reign. Many of these plants contain psychoactive agents, avoided by mammals today because of their bitter taste. Dinosaurs had neither means to taste the bitterness, nor livers effective enough to detoxify the substances. They died of massive overdoses.

3. Disasters: A huge asteroid struck the earth some 65 million years ago, lofting a cloud of dust into the sky and blocking sunlight, thereby suppressing photosynthesis and so drastically lowering world temperatures that dinosaurs and hosts of other creatures became extinct.

Before analyzing these three tantalizing statements, we must establish a basic ground rule often violated in proposals for the dinosaurs' demise. *There is no separate problem of the extinction of dinosaurs.* Too often we divorce specific events from their wider contexts and systems of cause and effect. The funda-

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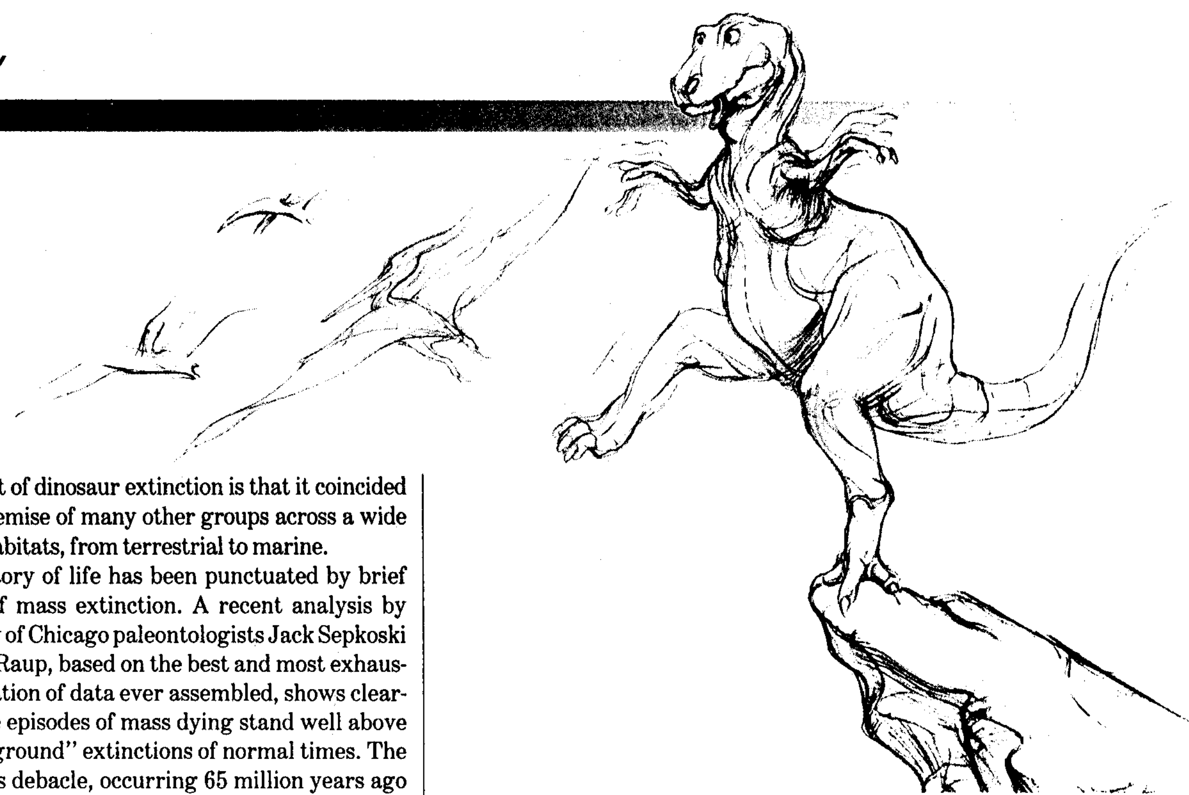

mental fact of dinosaur extinction is that it coincided with the demise of many other groups across a wide range of habitats, from terrestrial to marine.

The history of life has been punctuated by brief episodes of mass extinction. A recent analysis by University of Chicago paleontologists Jack Sepkoski and Dave Raup, based on the best and most exhaustive tabulation of data ever assembled, shows clearly that five episodes of mass dying stand well above the "background" extinctions of normal times. The Cretaceous debacle, occurring 65 million years ago and separating the Mesozoic and Cenozoic eras of our geological time scale, ranks prominently among the five. Nearly all the marine plankton (single-celled floating creatures) died suddenly, at least in geological terms; among marine invertebrates, close to 15 per cent of all families perished, including many previously dominant groups, especially the ammonites (relatives of squids in coiled shells). On land, the dinosaurs disappeared after more than 100 million years of unchallenged domination.

In this context, speculations limited to dinosaurs alone ignore the larger phenomenon. We need a coordinated explanation for a system of events that includes the extinction of dinosaurs as one component. Thus it makes little sense, though it may fuel our desire to view mammals as inevitable inheritors of the earth, to guess that dinosaurs died because small mammals ate their eggs (a perennial untestable speculation). It seems most unlikely that some disaster peculiar to dinosaurs befell these massive beasts—and that the debacle happened to strike just when one of history's five great dyings had enveloped the earth for completely different reasons.

The testicular theory, an old favorite from the 1940s, had its root in an interesting and thoroughly respectable study of temperature tolerances in the American alligator, published in the staid *Bulletin of the American Museum of Natural History* in 1946 by three experts on living and fossil reptiles—E. H. Colbert, my own first teacher in paleontology, R. B. Cowles, and C. M. Bogert.

The first sentence of their summary reveals a purpose beyond alligators: "This report describes an attempt to infer the reactions of extinct reptiles, especially the dinosaurs, to high temperatures as based upon reactions observed in the modern alligator." They studied, by rectal thermometry, the body temperatures of alligators under changing conditions of heating and cooling. (Well, let's face it, you wouldn't want to try sticking a thermometer under a 'gator's tongue.) The predictions under test go way back to an old theory first stated by Galileo in the 1630s—the unequal scaling of surfaces and volumes. As an animal, or any object, grows (provided its shape doesn't change), surface areas must increase more slowly than volumes—since surfaces get larger as length squared, volumes much more rapidly, as length cubed. Therefore, small animals have high ratios of surface to volume, while large animals cover themselves with relatively little surface.

"I'm not suggesting that dinosaurs OD'd on plant drugs, but it certainly was a factor." This psychoactive overdosing theory, simply untestable, will win a few press notices and fade into oblivion

Among cold-blooded animals lacking any physiological mechanism for keeping their temperatures constant, small creatures have a hell of a time keeping warm—because they lose so much heat through their relatively large surfaces. On the other hand, large animals, with their relatively small surfaces, may lose heat so slowly that, once warm, they may maintain effectively constant temperatures against ordinary fluctuations of climate. (In fact, the resolution of the "hot-blooded dinosaur" controversy of a few years back may simply be that, while large dinosaurs possessed no physiological mechanism for constant temperature, and so were not warm-blooded in the technical sense, their size and relatively small surface area kept them warm.)

Colbert, Cowles, and Bogert compared the warming rates of small and large alligators. As predicted, the small fellows heated up (and cooled down) more quickly. When exposed to a warm sun, a tiny 50-gram (1.76-ounce) alligator heated up one degree Celsius every minute and a half, while a large alligator, 260 times bigger at 13,000 grams (28.7 pounds), took seven and a half minutes to gain a degree. Extrapolating up to an adult ten-ton dinosaur, they concluded that a one-degree rise in body temperature would take 86 hours. If large animals absorb heat so slowly (through their relatively small surfaces), they will also be unable to shed any excess heat gained when temperatures rise above a favorable level.

The authors then guessed that large dinosaurs lived at or near their optimum temperatures; Cowles suggested that a rise in global temperatures just before the Cretaceous extinction caused the dinosaurs to heat up beyond their optimal tolerance—and, being so large, they couldn't shed the unwanted heat. (In a most unusual statement for a scientific paper, Colbert and Bogert explicitly disavowed this speculative extension of their empirical work on alligators.) Cowles conceded that this excess heat probably wasn't enough to kill or even to enervate the great beasts, but since testes often function only within a narrow range of temperature, he proposed that this global rise might have sterilized all the males, causing extinction by natural contraception.

The overdose theory has recently been supported by UCLA psychiatrist Ronald K. Siegel. Siegel has observed, he claims, more than 2,000 animals that can give themselves various drugs—from a swig of alcohol to massive doses of the big H. Elephants will swill the equivalent of 20 beers at a time, but do not like alcohol in concentrations greater than 7 per cent. In a silly bit of anthropocentric speculation, Siegel states that "elephants drink, perhaps, to forget . . . the anxiety produced by shrinking rangeland and the competition for food."

Since fertile imaginations can apply almost any hot idea to the extinction of dinosaurs, Siegel found a way. Flowering plants did not evolve until late in the dinosaurs' reign. These plants also produced an array of aromatic, amino-acid-based alkaloids—the major group of psychoactive agents. Most mammals are "smart" enough to avoid these potential poisons. The alkaloids simply don't taste good (they are bitter), and in any case we mammals have livers happily supplied with the capacity to detoxify them. But, Siegel speculates, perhaps dinosaurs could neither taste the bitterness nor detoxify the substances once ingested. Speaking of their extinction, he recently told members of the American Psychological Association: "I'm not suggesting that all dinosaurs OD'd on plant drugs, but it certainly was a factor." He also argued that death by overdose may help explain why so many dinosaur fossils are found in contorted positions. (Do not go gentle into that good night.)

Extraterrestrial catastrophes have long pedigrees in the popular literature of extinction, but the subject exploded again after a long lull three years ago when the father-son, physicist-geologist team of Luis and Walter Alvarez proposed that an asteroid, about six miles in diameter, struck the earth 65 million years ago. Most asteroids circle the sun in an orbit between Mars and Jupiter but some, the so-called Apollo objects, take a more eccentric route, actually crossing the earth's orbit in their path around the sun. The chance of a collision at any crossing is minuscule, but the number of Apollo objects and the immensity of geological time virtually guarantee that impacts will occur once in a great while.

The force of such a collision would be immense, greater by far than the megatonnage of all the world's nuclear weapons. In trying to reconstruct a scenario that would explain the simultaneous dying of dinosaurs on land and so many creatures in the sea, the Alvarezes proposed that a gigantic dust cloud, generated by particles blown aloft in the impact, would so darken the earth that photosynthesis would cease and temperatures drop precipitously. (Rage, rage against the dying of the light.) The single-celled photosynthetic oceanic plankton, with life cycles measured in weeks, would perish outright, but land plants might survive through the dormancy of their seeds (land plants were not much affected by the Cretaceous extinction, and any adequate theory must account for the curious pattern of differential survival). Dinosaurs would die by starvation and freezing; small, warm-blooded mammals, with more modest requirements for food and better regulation of body temperature, would squeak through.

All three theories, testicular malfunction, psychoactive overdosing, and asteroidal zapping, grab our attention mightily. As pure statements, they rank about equally high on any hit parade of primal fascination. Yet one represents expansive science, the others restrictive and untestable speculation.

How could we possibly decide whether the hypothesis of testicular frying is right or wrong? We would have to know things that the fossil record cannot provide. What temperatures were optimal for dinosaurs? Could the beasts avoid the absorption of excess heat by staying in the shade, or in caves? At what temperatures did their testicles cease to function? Were late Cretaceous climates ever warm enough to drive the internal temperatures of dinosaurs close to this ceiling? Testicles simply don't fossilize, and how could we infer their temperature tolerances even if they did? In short, Cowles's hypothesis is simply an intriguing speculation leading nowhere. The most damning statement against it appeared right in the conclusion of Colbert, Cowles, and Bogert's paper, when they admitted: "It is difficult to advance any definite arguments against this hypothesis." My statement may seem paradoxical—isn't a hypothesis really good if you can't devise any arguments against it? Quite the contrary. It is simply untestable and unusable.

Siegel's overdosing has even less going for it. At least Cowles extrapolated his conclusion from some good data on alligators. And he didn't completely violate the primary guideline of explaining dinosaur extinction in the context of a general mass dying—for rise in temperature could be the root cause of a general catastrophe, zapping dinosaurs by testicular malfunction and different groups for other reasons. But Siegel's speculation cannot touch the extinction of ammonites or oceanic plankton (diatoms make their own food with good sweet sunlight; they don't OD on the chemicals of terrestrial plants). It is simply a gratuitous, attention-grabbing guess. It cannot be tested, for how can we know what dinosaurs tasted and what their livers could do?

The hypothesis doesn't even make any sense in its own context. Angiosperms were in full flower tens of millions of years before dinosaurs went the way of all flesh. Why did it take so long? As for the pains of a chemical death recorded in contortions of fossils, I regret to say (or rather I'm pleased to note for the dinosaurs' sake) that Siegel's knowledge of geology must be a bit deficient: muscles contract after death and geological strata rise and fall with motions of the earth's crust after burial—more than enough reason to distort a fossil's pristine appearance.

The asteroid story, on the other hand, has a basis in evidence. It can be tested, extended, refined and, if wrong, disproved. The Alvarezes did not just construct an arresting guess for public consumption. They proposed their hypothesis after laborious geochemical studies with Frank Asaro and Helen Michel had revealed a massive increase of iridium in rocks deposited right at the time of extinction. Iridium, a rare metal of the platinum group, is virtually absent from indigenous rocks of the earth's crust; most of our iridium comes from extraterrestrial objects that hit the earth.

The Alvarez hypothesis bore immediate fruit. Based originally on evidence found in rocks at two sites in Europe, it led geochemists throughout the world to examine other sediments of the same age. They found abnormally high amounts of iridium everywhere—from continental rocks of the western United States to deep sea cores from the South Atlantic.

Cowles proposed his testicular hypothesis in the mid-1940s. Where has it gone since then? Absolutely nowhere, because scientists can do nothing with it. It merely stands as a curious appendage to a solid study of alligators. Siegel's overdose scenario will also win a few press notices and fade into oblivion. The Alvarezes' asteroid falls into a different category altogether, and much of the popular commentary has missed this essential distinction by focusing on the impact and its attendant results, and forgetting what is really important to a scientist—the iridium. If you talk just about asteroids, dust, and darkness, you simply tell stories no better and no more entertaining than fried testicles or terminal trips. It is the iridium—the source of testable evidence—that counts and forges the crucial distinction between speculation and science.

The proof, to twist a phrase, lies in the doing. In 35 years, Cowles's hypothesis led to no further advances toward our understanding of dinosaurian extinction. In three years, the Alvarez hypothesis has spawned hundreds of studies, a major conference, and attendant publications. Geologists are fired up. They are looking for iridium at all other extinction boundaries and, by the way, have not (with one exception) found any marked increases—thus proving that a good hypothesis also shows its worth by failing to work in other situations. Every week exposes a new wrinkle in the scientific press. In November a group of Yale scientists supported the hypothesis by finding a "cosmic signature" for isotopes of osmium in Cretaceous boundary rocks (a ratio of isotopes found in extraterrestrial material but not in crustal rocks produced on earth). Then, in December, chemists from the University of Maryland cast some doubt by reporting that volcanic eruptions of Kilauea on Hawaii had belched forth unexpectedly high levels of iridium; perhaps an extraterrestrial source need not be sought.

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My point is simply this: whatever the eventual outcome (I suspect it will be positive), the Alvarez hypothesis is exciting, fruitful science because it generates tests, provides us with things to do, and expands outward. We are having fun, battling back and forth, moving toward a resolution, and extending the hypothesis beyond its original scope.

As just one example of the unexpected, distant cross-fertilization that good science engenders, the Alvarez hypothesis made a major contribution to a theme that has riveted public attention in the past few months—so-called nuclear winter. In a speech delivered in April 1982, Luis Alvarez calculated the energy that a six-mile asteroid would release on impact. He compared such an explosion with a full nuclear exchange and implied that all-out atomic war might unleash similar consequences.

This theme of impact leading to massive dust clouds and falling temperatures was an important factor in the decision of Carl Sagan and a group of colleagues to model the climatic consequences of nuclear holocaust. We have, of course, long known that a full nuclear exchange could kill half of humanity outright and cannot be deemed acceptable on any grounds. But some of us still had lurking in our minds the hope that, if we hunkered down in our shelters and lived far from military sites or cities, at least we could survive after the initial fallout dropped.

Apparently, it is not necessarily so. Full nuclear exchange would probably generate the same kind of dust cloud and darkening that may have wiped out the dinosaurs. Temperatures would drop precipitously and agriculture might become impossible. Avoidance of nuclear war is fundamentally an ethical and political problem, but we must know the factual consequences to make firm judgments. Is this not a heartening thought: a recognition of the very phenomenon that made our evolution possible by exterminating the previously dominant dinosaurs and clearing a way for the evolution of large mammals, including us, might actually help to save us from joining those magnificent beasts in contorted poses among the strata of the earth. □