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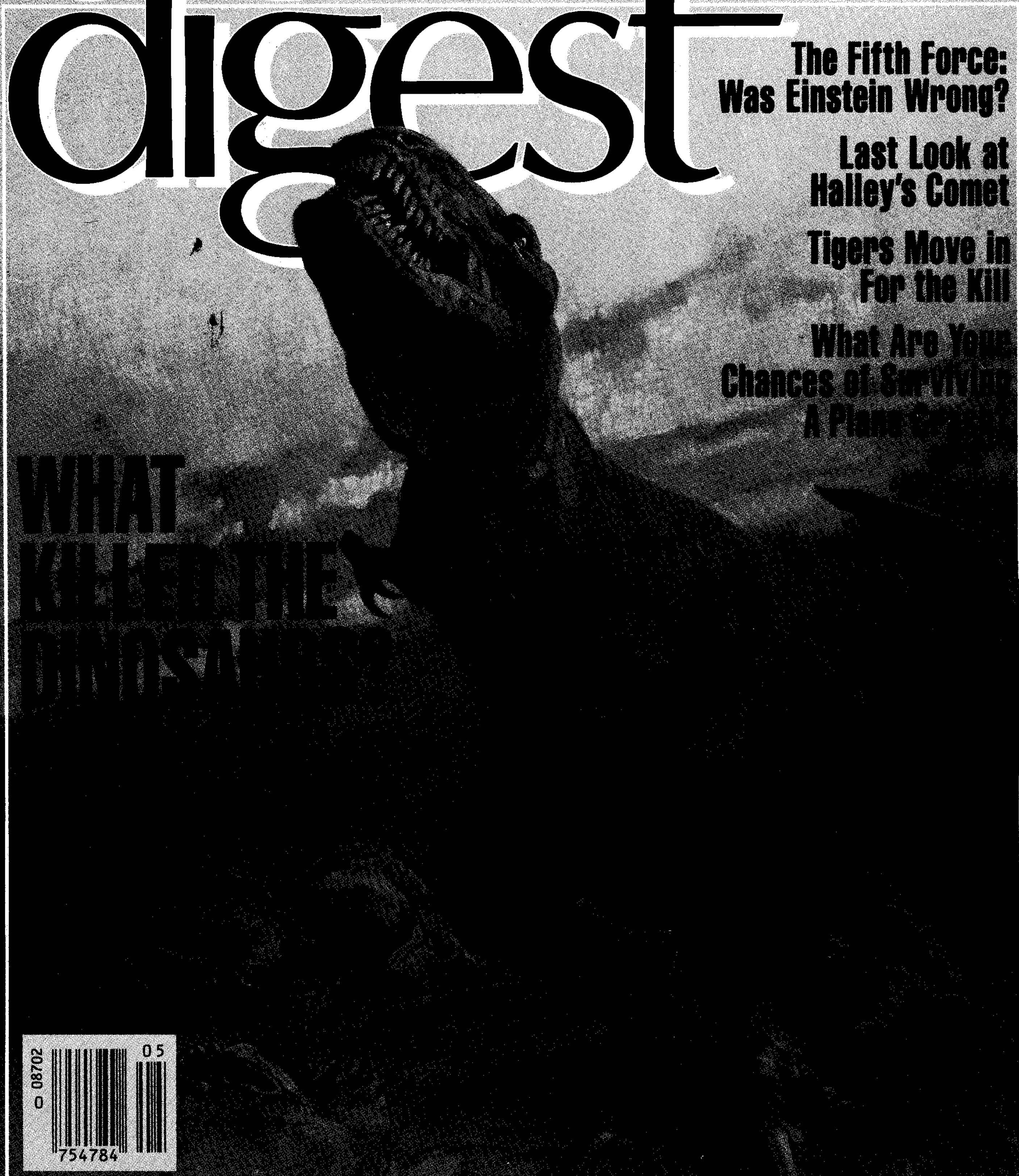
SCIENCE digest



The Fifth Force: Was Einstein Wrong?

Last Look at Halley's Comet

Tigers Move in For the Kill

What Are Your Chances of Surviving A Plane Crash?

WHAT KILLED THE DINOSAURS?

DEATH OF DINOS
THE TRUE STORY?

It is a sunny afternoon in the Late Cretaceous. Dinosaurs browse peacefully on tropical shrubbery under a warm sun. A tyrannosaur prowls the forest for dinner as hatchling hadrosaurs scamper around their nest.

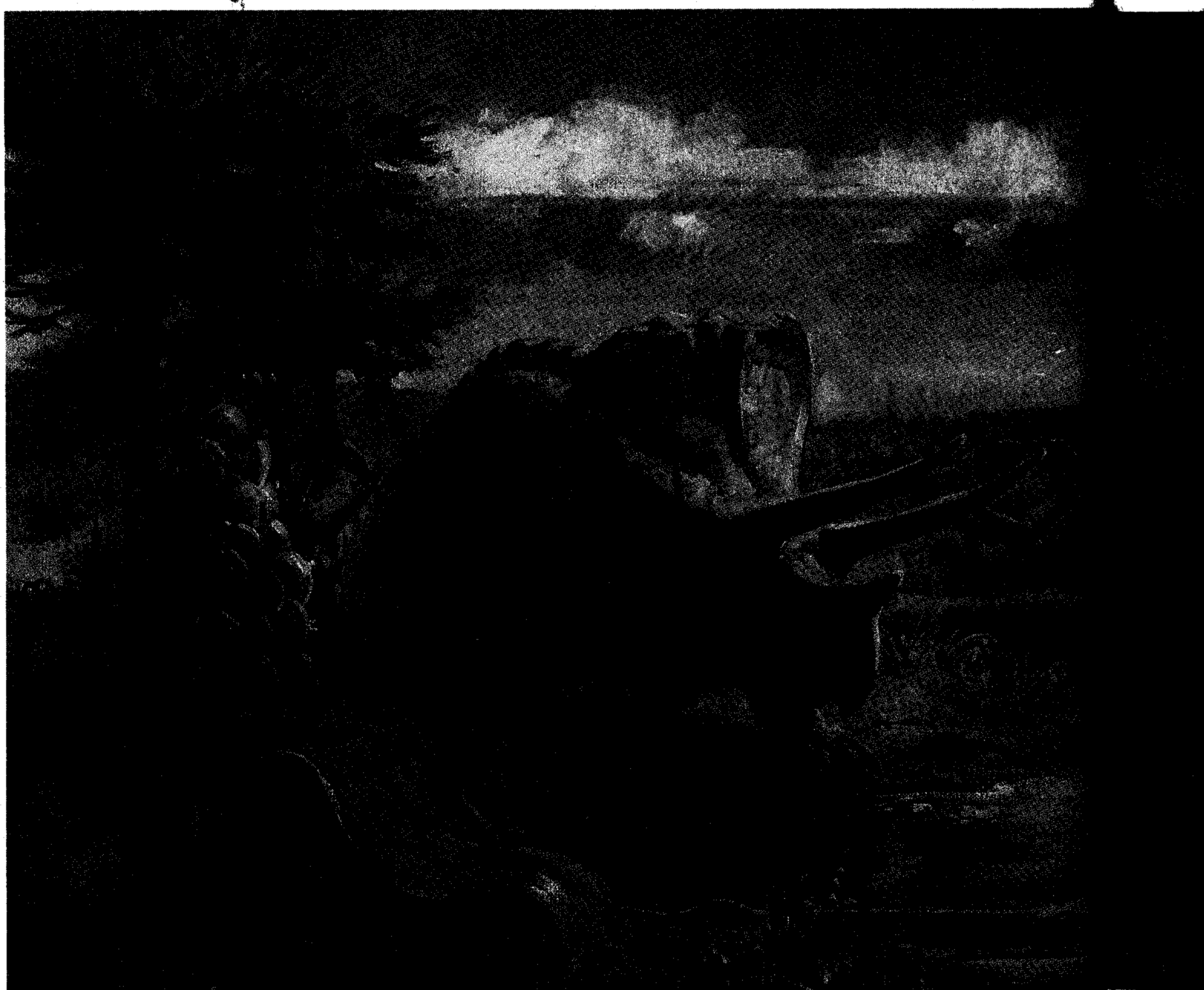
Suddenly the tranquility is shattered. A rock as big as a mountain crashes down from the sky with a world-wrenching boom. An ominous dust cloud mushrooms into the air.

Within days the black cloud spreads, darkening the sun. The air turns cold, and many dinosaurs die. Snow falls. Freezing darkness grips the Earth for weeks. Plants, cut off from the sunlight that feeds them, can't survive. Without plants, the rest of the herbivorous dinosaurs follow, and the carnivores soon afterward. Along with a number of other species, the dinosaurs are gone forever.

As a treatment for a science fiction movie, it would seem wildly improbable. But since the evidence supporting such a scenario started coming to light six years ago, it has gained wide acceptance—not as fiction but as science. The theory: A comet, asteroid or other huge extraterrestrial body slammed into the Earth 65 million years ago and ended the 160-million-year reign of the dinosaurs.

It wasn't necessarily a one-time phenomenon, either. Such disasters may happen according to a regular timetable and may have caused mass extinctions of species many times in history. If so, the textbooks on evolution—not just those on paleontology—may have to be rewritten.

Although many leading paleontologists and evolutionary biologists now



SAURS

BY BOYCE RENSBERGER/ILLUSTRATIONS BY ROY ANDERSEN

accept the asteroid-impact theory, and despite popular accounts implying that the question is settled, it is not. A scattering of critics continue to challenge the whole notion.

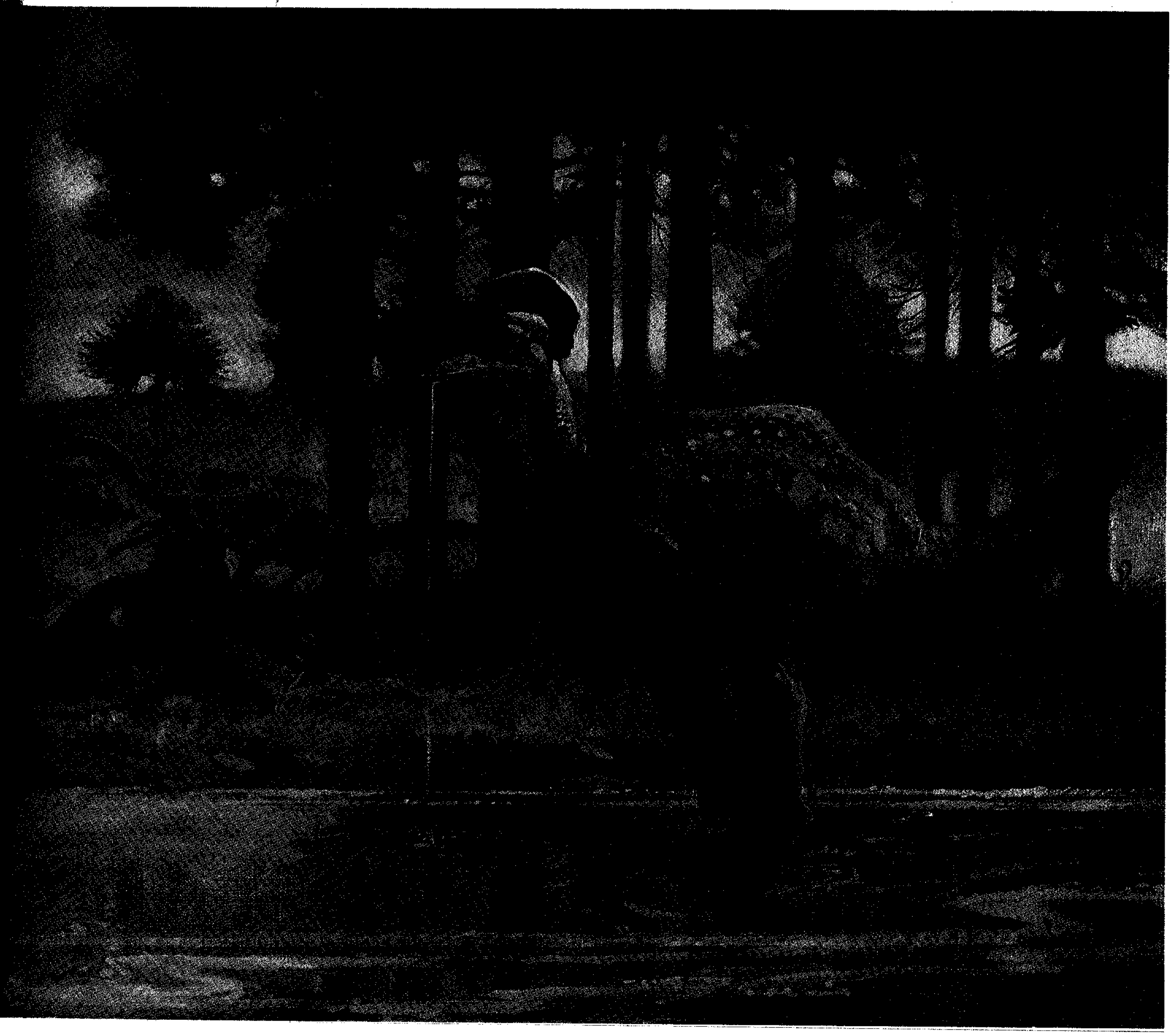
Still, the theory is compelling. Every few months a new piece of evidence is added to the list, and most, to the critics' consternation, support the idea of an extraterrestrial impact.

Just recently, for example, scientists at the Scripps Institution of Oceanography, in La Jolla, California, found evidence of organic molecules in the layer of sediments laid down at the time the dinosaurs died; the molecules are exceedingly rare on Earth but relatively common in some meteorites and so, presumably, in some asteroids.

To put the discovery in perspective, and to appreciate the arguments on both sides of the impact debate, one must first understand the nature of the original finding.

In 1980, Luis Alvarez, a Nobel laureate in physics, his son Walter, a geologist, both at the University of California, Berkeley, and two associates published the theory that a massive impact took place at the end of the Cretaceous. The team had found a rare substance in the thin layer of sedimentary clay deposited just on top of the highest, and therefore the most recent, stratum of rock contemporary with those bearing dinosaur fossils. It was the element iridium, which is almost nonexistent in the Earth's crust but 10,000 times more abundant in extraterrestrial rocks such as meteorites and asteroids. Deposits above and below the clay, which is the boundary layer separating the Cretaceous layer from the succeeding Tertiary, have

Boyce Rensberger, a AAAS-Westinghouse Science Journalism Award Winner for 1985, is profiled in Contributors, on page 6.



very little iridium.

Because the same iridium anomaly appeared in two other parts of the world, in clay of exactly the same age, the Alvarez team proposed that the element had come from an asteroid that hit the Earth with enough force to vaporize, scattering iridium atoms in the atmosphere worldwide. When the iridium settled to the ground, it was incorporated into sediments laid down at the time.

More startling was the team's proposal that the impact blasted so much dust into the atmosphere that it blocked the sunlight and prevented photosynthesis (others suggested that a global freeze would also have resulted). They calculated that the object would have had to be about six miles in diameter. (Soon afterward, scientists wondered whether a large number of hydrogen bomb explosions might have a similar effect. Calculations indicated they might, and the "nuclear winter" theory was born.)

Since 1980, iridium anomalies have been found in more than 80 places around the world, including deep-sea cores, all in layers of sediment that formed at the same time.

One of the more serious challenges to the extraterrestrial theory came up very quickly. Critics said that the iridium could have come from volcanic eruptions, which are known to bring up iridium from deep within the Earth and feed it into the atmosphere. Traces of iridium have been detected in gases escaping from Hawaii's Kilauea volcano, for example.

The new finding from Scripps appears to rule out that explanation, though, as a source for iridium in the Cretaceous-Tertiary (K-T) boundary layer. Chemists Jeffrey Bada and Nancy Lee have found that the same layer also contains a form of amino acid that is virtually nonexistent on Earth—certainly entirely absent from volcanoes—but abundant, along with

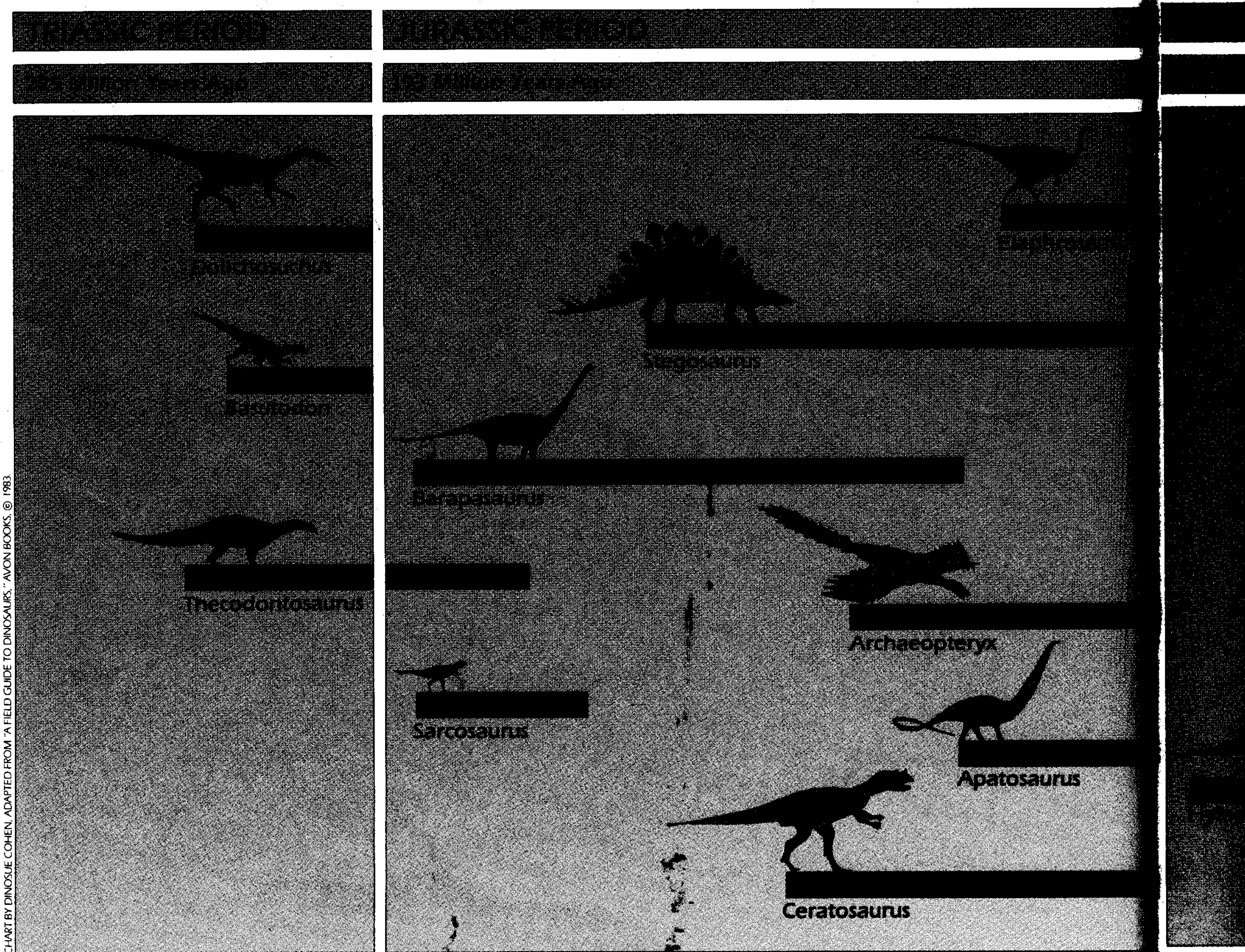


CHART BY DINOSUE COHEN, ADAPTED FROM "A FIELD GUIDE TO DINOSAURS," AVON BOOKS, © 1983.

IT APPEARS THAT THE DINOSAURS DIED OUT SIMPLY BECAUSE OF BAD LUCK.

many other organic compounds, in a type of meteor called a carbonaceous chondrite.

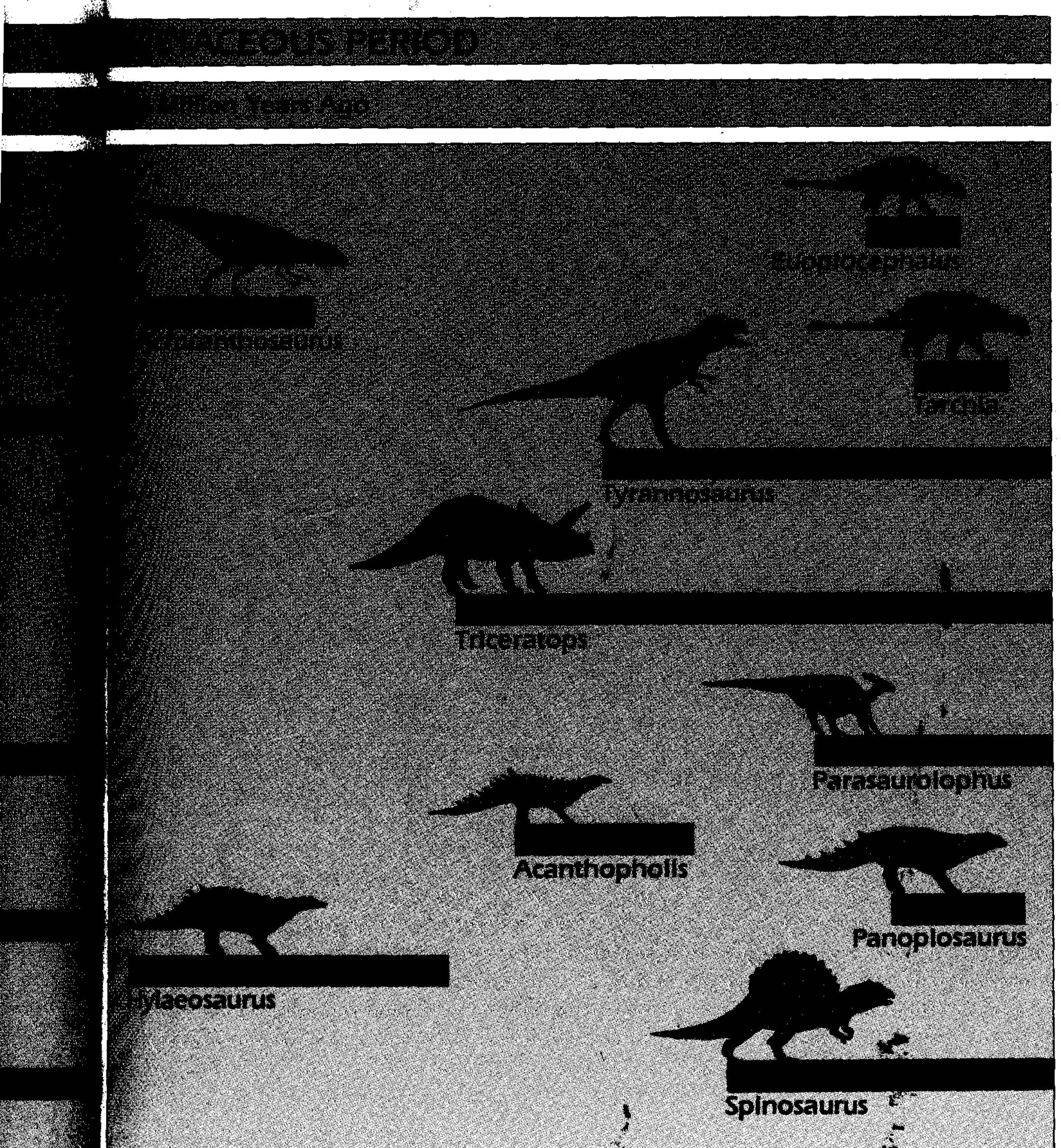
About 20 kinds of amino acids are used to build protein molecules in all known forms of life. The one Bada and Lee found, alpha-aminoisobutyric acid, was previously known only in two rare species of bacteria. Because this amino acid can be found mixed with the iridium and the clay particles that make up the boundary layer, Bada and Lee suspected it must have come from outer space—and the six-mile-wide object that the Alvarezes say hit the Earth may well have been a carbonaceous chondrite.

Even before the discovery by Bada and Lee, many evolutionary theorists had already declared themselves supporters of the impact story. They could envision how such an impact—or several such impacts, since there may have been a swarm of objects—would have triggered a global freeze. The sudden change, according to advocates of this view, led to one of the greatest mass extinctions in the history of Earthly life.

More significant still is the growing conviction among scientists that cataclysmic mass extinctions, perhaps brought on by similar events, are recurrent phenomena that have been playing a far more important role in the course of evolution than almost anyone had hitherto suspected.

Several mass extinctions are known from the fossil record, and there is evidence, though it's still not universally accepted, that they have occurred at regular intervals of about 26 million years. Indeed, some biologists now say that the notion of extraterrestrial impacts has already gained enough support that it could force a reappraisal of evolutionary theory, the kind of fundamental transformation called a paradigm shift.

If the impact theory holds up, then, it appears, in short, that the dinosaurs died out simply because of bad luck, not because there was anything wrong with them. They had dominat-



TERTIARY PERIOD

65 Million Years Ago

Fossil Evidence

The age of dinosaurs actually spanned three different periods in which individual dinosaur species came and went at various times. All three periods, however, ended with a mass extinction that wiped out many species simultaneously. The extinctions that ended the first two periods, the Triassic and Jurassic, nonetheless allowed some dinosaurs to survive and give rise to new species. The third mass extinction—the one that launched the controversy about a possible asteroid impact—left no undisputed dinosaurian survivors. The time bars in this chart, which shows only a few of the hundreds of dinosaur species, indicate only that period during which fossils of these species have been found. That some appear to have died out shortly before the end of the Cretaceous has led to the contention that this so-called mass extinction was not sudden but only the climax of a gradual process. Other scientists, claiming a sudden process, maintain that many of these species actually lived until the end of the Cretaceous but that their fossils have simply not yet been found.

–B.R.

ed the Earth for 160 million years and might have thrived right up to now. If they had, we probably wouldn't have been here to see them, for the event that closed the dinosaur era also opened the way for the evolution of primates and other higher mammals. Dinosaurs were well adapted to a largely tropical world, and almost instantly that world turned fiercely hostile for long enough to kill them.

No one really knows how long the dark, impact-induced winter might have lasted. It may have been over in a few weeks, or subtle but significant environmental disruptions may have persisted for thousands of years. In any case, the result was to wipe the ecological slate clean, or substantially so, in many parts of the world. As conditions improved, the surviving species found themselves with much wider ecological opportunities than before. Random mutations, which in the old world might have led to variant individuals that quickly died out, now spawned new species that easily found ways to survive.

Because of this effect, according to Harvard's Stephen Jay Gould, one of the leaders of modern evolutionary biology, the role of mass extinctions must be considered an important part of a revised theory of evolution.

"Mass extinctions," Gould wrote in his column in *Natural History*, "have been more frequent, more unusual, more intense (in numbers eliminated) and more different [in effect when compared with ordinary extinctions] than we had ever suspected. Any adequate theory of life's history will have to treat them as special controlling events in their own right."

Gould, an author of the theory of punctuated equilibria—which holds that most species arise in rapid bursts of evolutionary change and then remain largely stable for long periods afterward—now believes that his theory, which was first put forth with Niles Eldredge in 1972, must be supplemented by an understanding of the completely separate phenomenon of mass extinctions.

According to Gould, punctuated equilibrium is the rule during the periods between mass extinctions. But, "whatever accumulates by punctuated equilibrium in normal times can be broken up, dismantled, reset and dispersed by mass extinction." Once large areas of the slate have been wiped clean, the less cataclysmic processes of biological evolution proceed to write anew, filling them up again.

Mass extinction, then, sets the stage for many bursts of rapid evolution and the creation of entirely new forms of life. Like Siva, the Hindu god

Are Dissenting Views Being Suppressed?

Rivaling in importance the purely factual aspects of the great extinction debate has been a more personal and highly emotional issue. Some critics of the extraterrestrial-impact theory charge that their views are being withheld, kept out of scientific journals and meetings for political and other unscientific reasons.

The critics do not agree uniformly on the points of the controversy, but perhaps the most serious charge is that criticism of the impact theory is being suppressed because it is seen as implicit criticism of the highly politicized "nuclear winter" theory.

The reasoning is as follows: The nuclear-winter theory originated as an offshoot of the extraterrestrial-impact theory. If debris from a comet impact could trigger a global freeze, so could debris from a nuclear war. Computer simulations supported the link. Those scientists who are also anti-nuclear war activists, and therefore naturally receptive to any argument against the survivability of nuclear war, were quick to rally behind the linked theories of nuclear winter and impact extinction.

Critics of impact extinction argue that control of scientific journals is predominantly in the hands of the antiwar activists and that, therefore, the journals are disinclined to publish articles that cast doubt on the impact-extinction theory.

Though complaints about alleged bias on the part of journals have been voiced informally at some scientific meetings, there is little objective documentation that critical papers have been rejected for improper reasons. Indeed, several scientists on both sides of the issue said they could not cite specific cases of bias or exclusion from journals or meetings, even though nearly every scientist interviewed on this question mentioned [illegible] and was granted anonymity.

"I'm not aware of any bias," said one evolutionary biologist who [illegible] on the issue and who regularly evaluates grant proposals for the National Science Foundation, as well as reviewing manuscripts for two prominent journals in the field.

"I don't think there's an overt covering up or torpedoing of other people's views," says Keith Rigby, a paleontologist at the University of Notre Dame. Instead, the problem seems to be that older, established paleontologists are finding their sleepy field suddenly invaded by young, eager hotshots from other fields—geochemistry and astronomy, for example. At least one scientist feels part of the reason is that paleontology has lagged behind other fields in getting up to speed on the newest research methods, and many are hostile toward the interlopers.

Another scientist, definitely a critic of the impact theory, says the grumblings have not generally come from the leaders on either side. "Walter [Alvarez] has played this just about as straight as he can," he says. "The argument has polarized the second- and third-tier people." He notes also that when granting agencies ask outside scientists to review grant requests, they typically avoid going to prominent advocates for one side or the other. Instead, they rely on reviews by less visible scientists who are presumed to be less committed to a single view.

In reality, the critic says, these people are not neutral. In fact, they are often junior people who are more easily offended and upset by contrary views than their more experienced colleagues would be.

–B.R.

SOME PALEONTOLOGISTS MAINTAIN THAT THERE NEVER REALLY WAS ANY MASS EXTINCTION.

of destruction, mass extinction is what makes possible the processes of creation through a continuing cycle of destruction and renewal. Indeed, though a mass extinction destroyed the dinosaurs, it was an earlier mass extinction (or extinctions) at the end of the Permian Period 225 million years ago that closed the age of the amphibians and made the world available for the dinosaurs to arise and diversify.

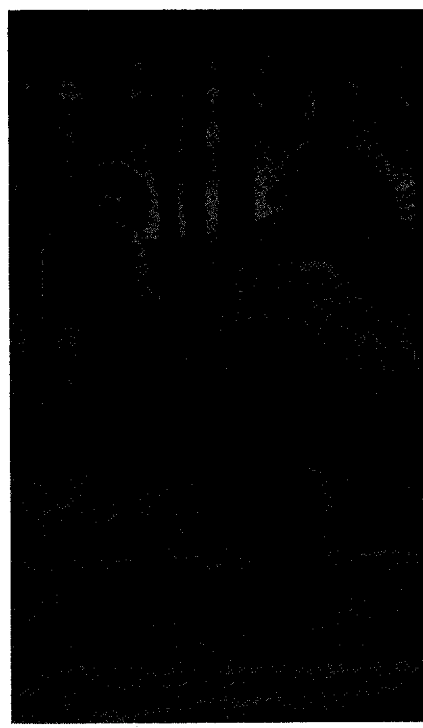
It was the evidence for repeated mass extinctions that led in 1984 to a theory of cyclical cataclysms. Two paleontologists at the University of Chicago, David Raup and J. John Sepkoski, Jr., gathered all the evidence on reliably dated, documented extinctions over the last 250 million years. Computer analysis revealed that the rate of extinctions was not constant. Instead, it rose and fell through 12 peaks. Eight of the peaks fit closest to a 26-million-year cycle.

To Raup and Sepkoski this suggested that some regular process might be at work, some natural cycle of incredibly long duration that visited mass destruction upon the Earth at periodic intervals. Because no Earthly cycles are known to take so long, many scientists turned to the heavens.

Thus was born Nemesis, a hypothetical, unseen companion star to the sun, named for the Greek goddess of vengeance. Marc Davis and Richard Muller of the University of California, Berkeley, and Piet Hut of the Institute for Advanced Study in Princeton proposed that Nemesis' elliptical orbit brings it close enough to the solar system every 26 million years to trigger a hail of comets. Astronomers believe that a cloud of billions of comets circles the sun far beyond Pluto's orbit. An approaching companion star, they speculated, might exert enough gravitational pull on the comets to disrupt their orbits and send some of them careering toward the sun. Once every 26 million years or so, in this scenario, one or more comets might happen to come close enough to the Earth to hit it.

More recently, however, Hut has argued that any companion star that traveled far enough from the sun to fit this orbit—it would be 2.5 light-years away at the farthest—would be so loosely bound by the sun's gravity that it would be torn away within a billion years. This has convinced many scientists that the chances that Nemesis exists are slim. Hut, though, maintains his theory is still viable.

Still another speculation, offered by Daniel Whitmire and John Matese of the University of Southwestern Louisiana, proposed Planet X, an undiscovered tenth planet that might orbit the sun within a tunnel through the



comet cloud. Changes in the orientation of its eccentric orbit, they suggested, might bring it near enough to comets every 26 million years to pull them out of orbit and send them Earthward.

This idea, too, has fallen on hard times. The University of Toronto's Scott Tremaine says that any planet big enough to clear a gap in the comet cloud would pull more distant comets into the gap, filling it again. Unless the gap stayed devoid of comets, there could be no sudden grazing of the cloud to trigger a comet shower.

A third speculation came from Michael Rampino and Richard Stothers of NASA's Goddard Institute for Space Studies in New York City. They invoked the fact that the solar system, rather like a horse on a merry-go-round, bobs up and down as it revolves around the center of the Milky Way, passing through the central plane of the galaxy about every 33 million years. Because the galactic plane is dense with drifting gas and dust clouds, it was argued that the collective gravitational pull of the clouds might have dislodged comets.

But once again there were counterarguments. Patrick Thaddeus and Gary Chanan of Columbia University have argued that the clouds are so wide that the solar system never really goes far enough to one side to experience a distinct pull in one direction. Moreover, some scientists think the 33-million-year cycle is too far from 26 million years to allow a correlation. Stothers counters that the clouds are indeed narrow enough and that the latest analysis puts the cycle at 30 million years.

At the moment, then, there is no completely convincing explanation of what might have caused periodic comet showers. Astronomers and astrophysicists, however, are almost as notorious as evolutionary theorists for finding new evidence and making new calculations that alter current thinking. Almost certainly, one or more of these ideas will find new support and reemerge as a viable candidate—or an entirely different one will appear.

Meanwhile, back on Earth, the mystery of dinosaur extinction continues to embroil paleontologists and others on all sides of the debate.

Perhaps the most extreme opposition to the extraterrestrial theory comes from paleontologists who maintain there never really was any mass extinction.

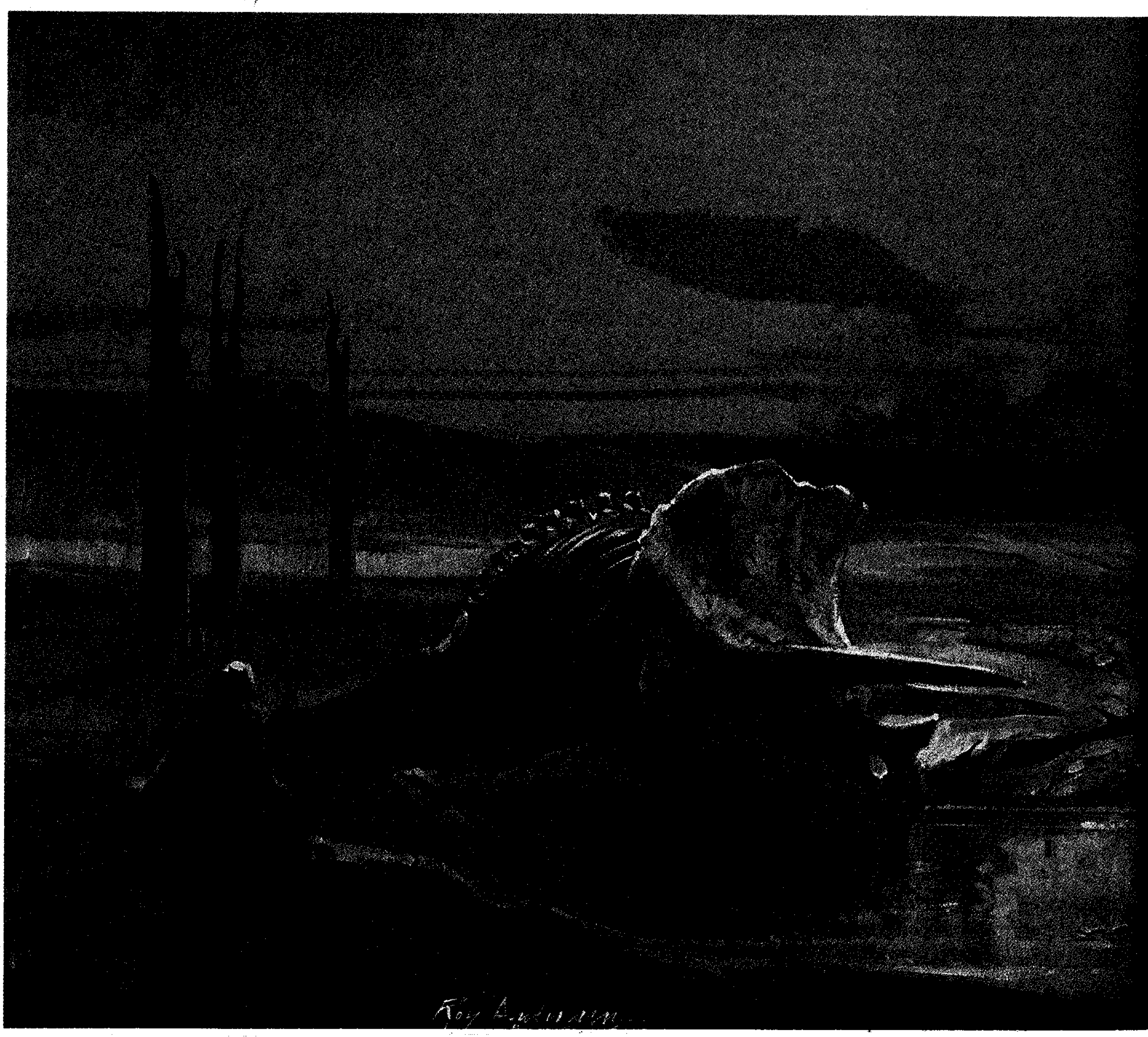
"I think what we're looking at is no great catastrophe," says Dewey McLean of Virginia Polytechnic Institute. McLean believes that instead of a sudden catastrophe, the Late Cretaceous witnessed a gradual increase in the rate of species extinctions, which merely peaked at the K-T boundary and then slowly declined to a more normal rate. McLean maintains that his pattern holds for dinosaurs as well, except that the last of the dinosaur extinctions took place soon after the K-T transition.

If the extinctions came gradually, the cause must have operated gradually, McLean reasons. The culprit in his view is not a one-shot impact but a slow increase in volcanic eruptions, which poured so much carbon dioxide into the atmosphere that it induced a greenhouse effect. Carbon dioxide allows sunlight to heat the Earth but slows the radiation of excess heat back into space. There is evidence that there was a global warming at the time of the K-T transition.

"I think I've discovered a link between air temperature and extinctions," says McLean. "It involves reproductive endocrinology." He speculates that a warming climate interfered with the formation of dinosaur eggshells, making them thinner and eventually nonexistent. "Dinosaur eggs are a lot like chicken eggs," McLean says. "People in poultry science will tell you that in the summer, when it gets real hot, it affects chickens' calcium metabolism, and eventually they can stop laying."

While there is preliminary evidence that the shells of one dinosaur species were thinning toward the end of the Cretaceous, there is nothing to suggest that it applies to any other species, and most paleontologists dismiss this hypothesis.

Another believer in the relatively gradual extinction of dinosaurs is Notre Dame's Keith Rigby, Jr. He, like many critics of the Alvarez team's theory, accepts that there was an extraterrestrial



"YOU LOOK THREE INCHES UP AND YOU CAN TELL THE WORLD HAS CHANGED."

impact but not that it was the sole cause of dinosaur extinction.

"There is not much question that something did happen," Rigby says, referring to the impact. "The debate is about what the results were. Most of us will admit that in all probability the impact had some influence. It's just that we don't all agree it was catastrophic. I started solidly in the Alvarez camp, but I've migrated as new data come on the scene. There was a great impact, but it hit in the midst of a situation that was already fraught with change."

As evidence of the change, Rigby cites his own discoveries of dinosaur fossils in Montana, which decline both in number of species and in overall quantity over the last few million years before the K-T boundary. The greatest diversity occurred about 10 million years before the supposed mass extinction, but by the last few years before it happened, between half and two-thirds of the dinosaur species had already disappeared from the fossil record.

Other scientists caution that the appearance of a gradual decline in species can be deceptive. David Jablonski of the University of Chicago, for example, says the deception can emerge from a combination of natural circumstances preceding a mass extinction. He notes that mass extinctions often follow long periods of falling sea level. While this itself may be related to climatic changes that make life difficult for many species, Jablonski observes that it also has the effect of shrinking the area in which fossils are preserved.

Bones, shells and other fossils are preserved when they get trapped in aquatic or marine sediments and become part of the sedimentary rock. But when sea levels are declining, smaller areas of sediment are preserved. Even though species may still be living, the chances decrease that they will be preserved as fossils and found by paleontologists.

Continued on page 77

Continued from page 35

Jablonski has found that many taxonomic groups whose remains disappear from the fossil record during periods of falling sea level will be found again in sedimentary rock that formed much later, when sea levels were rising again. He calls these reappearing species "Lazarus taxa."

Thus, many of the species that seemed to become extinct long before the putative extraterrestrial impact may simply have lived on quite happily without leaving proof that they did so. Extinction during the missing interval could have been gradual, says Jablonski, or could have come at the instant of impact.

Jablonski has also found another form of evidence to indicate that mass extinctions are real. He has discovered significant differences between the species that died out during mass extinctions and those that disappeared during normal times.

The difference between the two groups, Jablonski reasons, is their tolerance for a wide variety of ecological niches. The species that succumb during a mass extinction belong to families that have many closely related species, a situation that is thought to arise because each is adapted only to a narrow ecological niche. Having little tolerance for ecological change, these species are the ones that suffer most during mass extinctions.

Groups that have wide tolerances, by contrast, tend to evolve fewer species that are more specialized because the existing forms already occupy a variety of environments. Because they are more tolerant of environmental variations, they are less vulnerable to the extreme environmental shifts that cause a mass extinction.

Jablonski concludes that mass extinctions are qualitatively, and not just quantitatively, different from "normal" extinctions. There must be something special that happens in a mass extinction.

He dismisses the notion that sudden wipeouts do not occur. "I just can't see any way to maintain there wasn't a mass extinction," he says. "You look at the reefs in the Caribbean, at the fossils from the Cretaceous, and you look three inches up and you can tell the world has changed."

The change on land may have been even more dramatic than early reports indicated. Just recently, scientists at the University of Chicago found evidence that heat generated by the impact ignited vast firestorms that raged across much of the Earth.

The evidence is in an unusually high density of soot particles found in the K-T boundary layer. The soot, fluffy particles of elemental carbon, which is known to be produced by forest fires, has been found in locations as far apart as Denmark, Spain and New Zealand. The discoverers, Edward Anders, Wendy Wolbach and Roy Lewis, have calculated that the boundary layer contains about 10,000 times as much soot as normally accumulates from isolated forest fires. To produce this much, they say, the fires must have burned essentially all the Earth's vegetation.

BOOK JACKET COURTESY CHARLES SCRIBNER'S SONS

The heat of impact would have scattered white-hot rock for 1,000 miles, setting a vast area ablaze.

The Chicago team has calculated that if the Earth was struck by a six-mile-wide object, the heat of the impact would have scattered white-hot particles of rock as far as 800, and possibly 1,200, miles around, setting the entire area ablaze.

"Once started," they write in *Science* (October 11, 1985), "such a fire could spread over an entire continent, and the resulting winds may disperse the soot worldwide."

Still, not everyone accepts that the world changed so suddenly as to exclude dinosaurs at a stroke. Rigby says that some of the dinosaur fossils he has found, isolated teeth from 13 different species, came from deposits above the iridium layer. If that is really where they were originally deposited, when their owner died, it would be proof that some dinosaurs survived the impact, though not by very long.

Other fossil experts cast doubt on Rigby's claim by observing that fossils do not always stay in the same layer in which they were first deposited. Geologic uplifting can raise old fossils above nearby younger layers and allow erosion to wash them out and down on top of those layers. Subsequent sedimentation can cover them up and make it look as if they were there all along.

For this reason, paleontologists often distrust the provenance of fossils found as isolated bones or teeth, which could have been separated by these processes from the rest of the skeleton. If many bones from one individual are found in one place, it is more likely that geologic reworking has not confused the situation.

More troublesome is the recent report by Berkeley's William Clemens of hadrosaur bones found on Alaska's North Slope.

"Well, Professor, it looks like your experiments with a universal solvent are proving to be a success."

CARTOON BY SAM GROSS

DINOSAURS

The site was at least as far north in Cretaceous times, and the find suggests that dinosaurs must have already had some form of adaptation, perhaps hibernation, for riding out the long dark winters at that latitude. Clemens argues that the beasts, therefore, could have survived an asteroid-induced winter.

But even critics of the mass-extinction theory have trouble with this find. Rigby, for one, says he cannot imagine how a dinosaur could live at that latitude, even in the absence of impact effects. "Where would he go in the winter?" Rigby asks. "It's kind of tough."

It would be unusual in science if the great dinosaur debate were resolved quickly. Science isn't like that. While individual scientists may advocate their interpretations with great passion, the true progress of science usually follows a long period of evidence gathering on both sides that eventually yields a preponderance fitting one theory. Even then, of course, there are always diehards who find themselves outside the mainstream.

The six years since the Alvarez team first proposed their theory have already witnessed remarkable productivity on the part of scientists in many fields, including fields once far removed from the study of old bones.

Yet there is already a hint of the kind of evidence that could go a long way toward clinching not only the impact theory of dinosaur extinction but, as well, the periodic contribution of extraterrestrial forces to the changing history of life.

There is preliminary evidence that iridium anomalies exist in sedimentary layers that correspond to five other mass extinctions. There is a strong iridium layer at the end of the Eocene, but the extent of that extinction was mild. Chinese scientists have found one at the end of the Permian, when the greatest mass extinction of all occurred, but in this case the iridium data are questionable. A Polish group has found an anomaly corresponding to a mass extinction between the Middle and Upper Jurassic. And an Australian team has found one toward the end of the Devonian.

If one or more of these can be pinned down to everybody's satisfaction, it would be very hard to deny a relationship between the impact of extraterrestrial objects on Earth and mass extinctions.

"These are very tantalizing possibilities," says Raup, an author of the 26-million-year-cycle theory, "but every one is debatable."

Debate, however, is the engine of scientific advancement, and there is every reason to think that one of the greatest mysteries in the history of life is lurching toward a solution. ■

Air Safety

Continued from page 55

cedure has already been tested successfully on white gasoline, a fuel described by Bayless as far more volatile than jet fuel.

Many military aircraft protect against spillage by containing their fuel in a huge, tear-resistant synthetic rubber bladder in the wing. In commercial jets, however, bladders are considered impractical because of the added cost and the required modification of the wing.

While fuel experts struggle with ways to prevent postcrash fires, other researchers concentrate on means to reduce casualties once fires occur. In the world's largest enclosed aircraft fire-test facility, at the FAA Technical Center, research continues on how aircraft fires originate and develop and how they can be dealt with. Inside the cavernous structure, a dismounted C-133 transport is repeatedly rigged with cabin furnishings, seats and dummies, which technicians set fire to and then extinguish to measure the results.

In postcrash aircraft fires, the life-threatening hazard is a phenomenon called flashover. When fire enters or breaks out in the passenger compartment, smoke and heat build up in the enclosed space and hover near the ceiling. Eventually this heat becomes so great that the cabin materials reach their ignition point and burst into flame and escape becomes impossible. "Within seconds," says Gus Sarkos, FAA Technical Center fire safety branch manager, "the situation changes from survivable to almost surely fatal."

FAA regulations require that passengers be able to evacuate an aircraft cabin within 90 seconds using only half the exits. According to Sarkos, the time available to escape a burning cabin could be lengthened by one to "several" minutes by reducing the flammability of the cabin furnishings. James Danaher of the survival factors division of the NTSB agrees. "The real payoff in survivability is to afford more time before the situation becomes intolerable," he says.

Sarkos was pleased with at least one aspect of the CID experiment: Motion pictures and the seats themselves confirmed that materials previously tested by the fire safety branch could in fact retard seat-cushion burning. Polyurethane seats have been a particular target of fire investigators because the lightweight, resilient, durable substance is used in virtually all commercial aircraft seating. But when set afire, polyurethane burns rapidly with intense heat and gives off thick smoke that hampers visibility. Yet there is no obvious economical substitute. So the FAA has tested numerous fire-blocking fabrics, which fit over the cushion "like a pillowcase," says Sarkos, and can retard burning for at least 60 seconds. Fire-blocking layers will be required on all transport seats after November 1987. Fire-resistant coverings for cabin walls and ceilings have also been developed and should delay flashover for several more minutes.

Also, low-level floor lights will be required on jets by this November. As Sarkos notes, even uninjured persons become disoriented and can lose precious seconds as they try to grope through a cabin where rising smoke has obscured the overhead lights. Situated beneath the smoke level, the lights will illuminate the pathway and mark escape routes.

While postcrash fires are responsible for many deaths, inflight fires are also a hazard. FAA regulations effective this year require that all jets carry two fire extinguishers containing Halon 1211, a more effective extinguishing agent than previously used. FAA researchers plan to study new devices, including an interconnected smoke detector and extinguisher that would be set into the walls near hidden fire-vulnerable areas and flood an unseen fire with smothering chemicals.

Emergency smoke-evacuation procedures are also under scrutiny. As Sarkos notes, current procedures include the opening of windows or the emergency hatch to vent the airplane of visibility-obscuring smoke. But the flood of fresh air might deliver oxygen to the fire. In fact, just such an event occurred aboard a Varig Airlines 707 in 1973. The pilots, noting smoke in the cabin and reports of a fire somewhere, consulted their manuals and opened a window to deal with the smoke. The plane crashed near Paris, killing 123 people. While it is not known that the pilots' reaction intensified the fire, Sarkos says, "Clearly, we need to get a handle on better emergency procedures."

The third aspect of crashworthiness concerns keeping the plane in one piece on impact. In the CID experiment, the 720 did not break apart despite the nose-down impact; and the underbody crushed and absorbed much of the energy, which presumably would have protected passengers from injury or death. Information from the sensors confirmed previous data charted by Caiafa and Thomson and collected in static tests. "Basically, the airframe seems to be doing its job of providing a protective shell," says Danaher of the NTSB.

At both Langley and the FAA Technical Center, engineers have been dropping sections of fuselage to measure the forces of impact. At Langley, they used a 70-foot drop tower, from which 10-to-12-foot circles of fuselage were lifted and dropped onto reinforced concrete at rates of up to 20 feet a second. Tests have shown that the "soft" sections of fuselage, those forward and aft of the wings, will buckle on impact and collapse inward two or more feet. This absorption of injury can cut in half the force transmitted to passengers. FAA Tech Center tests revealed that when luggage is stowed in the compartments under the cabin, the energy load is further reduced. The stiffer wing box area, however, does not crush, so impact forces are slightly higher in that part of the cabin.

According to the NTSB report, failure of the seat-restraint system allows "the occupant to become a missile traveling at essentially the same velocity as the aircraft just before impact." The study, as charted by the investigators, cited seats ripped loose from their anchorage; backs broken; legs collapsed; belts that failed at the buckle or at the attachment points. The report pointed out that the problem was not simply one of serious injuries caused by seat failure. Even slight injuries could prevent passengers from evacuating the plane quickly, and damaged cabin furniture could obstruct their route.

In half of the 99 survivable crashes investigated by Caiafa and Thomson, some portion of the seat-restraint system failed. Caiafa, years ago an FAA accident field investigator, recalls one accident in which a transport plane struck a house with such force that almost all the seats ripped loose and passengers flew through the air and piled one on top of the other against the cockpit bulkhead. Those on top were cushioned from death by the bodies of those beneath. But seat failures can be protective as well as hazardous, he says. In at least half of those survivable accidents, according to Caiafa, the NTSB classified seat failure as a deformed seat, when in fact a seat that deforms or stays in place could be beneficial. "The NTSB considers it a failure when the seat legs collapse," he declares. "Wrong. Collapse is beautiful. The primary purpose of a seat is to protect the occupant. When the legs buckle and absorb some of the accelerative force, the seat is doing its job."

By FAA regulations, now 30 years old, seats must be able to withstand a force of 9 g's (nine times the weight of the passenger in the seat) in a forward direction, 4.5 g's downward, 1.5 g's sideward and 2.0 g's upward. Actually, says Caiafa, decelerative forces seldom occur in a single direction or in steady amounts. Instead, they may pull in several directions simultaneously or serially and hit peaks far higher than the average pull. At this point, the time or duration that the load is being applied is critical. In the CID test, FAA researchers installed a test seat whose legs would telescope at 9 g's and absorb any greater force; another seat was fitted with pivoting attachments instead of stationary

Seats ripped loose, their backs and legs broken. The belts had failed, too.

fittings at the floor so that it could move in different directions to accommodate any floor warpage. These two seats were burned beyond recognition, however, so a detailed analysis could not be made.

The question of how much force the human body can stand without permanent injury is still being argued. Some tests indicate that the body can absorb as much as 20 g's in the pelvic area for 0.1 second; the NTSB says that seats are tested for only half that amount. This means they could tear loose and cause injury even though the passenger might otherwise emerge unhurt. Other engineers say body tolerance is deceptive. While it is thought that young adults can absorb more g forces than older adults, the pattern of the impact may have just as much bearing as the force itself. A Boeing engineer recalls an accident in which a DC-9 ran off the Toronto runway when the brakes had to be suddenly applied following a tire failure, causing the plane to fall into a ravine. "It was the equivalent of falling off a six-story building," he says, "and most of the people didn't even get their hair mussed."

Another important target for engineers is to eliminate as many potentially lethal objects from the passenger space as possible. Luggage compartments often spring open on impact: packages or suitcases can cause injury, but even soft objects like pillows may temporarily surprise the passenger or block the aisles and exits. A number one priority for manufacturers has been to install safety catches to keep compartments closed in a crash.

To most aircraft safety researchers, the events of 1985 were an unfortunate oddity, a blip on the descending slope of aircraft fatalities unlikely to be repeated. Still, they agree that there are no sure answers in crash survival and that the dynamic field is likely to produce new problems and challenges. Already, both the FAA and NASA have begun studying crash-impact effects on advanced composite materials, now being used on small aircraft and expected to play a bigger part in transport aircraft of the future. While these weight-saving materials are many times stronger than steel, they are also more brittle; instead of deforming or twisting, they may simply snap. Or, because they are formed in thin layers, they may delaminate or tear.

Moreover, most fuselage testing has been done with narrow-body aircraft, such as 727s, 737s and the CID's Boeing 720. Only recently has the FAA begun to drop-test wide-body sections, which are larger and heavier. In fact, in the first DC-10 test, says one engineer, the test section "bounced, then bounced again and then rolled like a tin can."

Danaher of the NTSB notes that usable data on crash survivability are difficult to come by. "Crashes are such rare events—and each is almost unique—that it is sometimes difficult to see a pattern," he says. In addition, the human factor in real situations tends to muddy the laboratory findings. "You hear a lot of bad-mouthing about carry-on luggage," he says. "But part of the problem is the people, who don't want to be separated from it. In a crash of a Continental DC-9 in Los Angeles, when the plane was already burning, some people actually stopped to take their briefcases out of the racks."

Yet engineers remain convinced that ways can be found to protect passengers and save lives in many of today's crashes. They note that a helicopter is being designed for the Army that should be able to hit the ground at the rate of 42 feet a second without serious injury to the crew. Some of the same principles might be applied to transport aircraft, they say.

"There will always be some crashes we cannot protect against," one safety engineer says. "When a plane plows into a mountain, you're not going to have many survivors." But as the case of Yumi Ochiai shows, survival can happen—and is worth striving for. ■