Extinctions
HE WAS THE LAST of the free fliers, this ungainly bird his captors nicknamed Igor. His keepers now wing when they hear him called that. California condors are supposed to have local Indian names.

Chumash. Miwok. Pomo. For time beyond memory Indians throughout the West have regarded the condor as a god. His spirit, some say, inspired legends of the thunderbird, whose flight is responsible for the weather. Thunder is the flap of his wings, lightning the flash from his eyes. Today Igor’s eyes, as he perches in his pen at the San Diego Wild Animal Park, are the eyes of extinction.

Igor, officially titled AC-9, for adult condor number nine, was the last wild survivor of his species. Amid great controversy he was trapped in April 1987 and brought to wait—and, zoo officials hope, to breed—along with a few comrades, until the world might once again be safe for condors.

Igor’s flying prowess fires public opinion. Since the 1930s millions of dollars have been spent to save California condors and preserve their habitat. That power has bought the condors time—to sit, remote from human contact, in this large fenced enclosure. Other creatures have not fared as well. Since Igor’s capture the dusky seaside sparrow disappeared from the planet. During that same time as many as a hundred acres a minute of the world’s tropical forests, among the most richly populated habitats on earth, have been destroyed. Ecologists can only speculate about how many unnamed, unknown creatures have vanished with the trees. An estimated million species will be lost in the next 25 years—a rate of one every 15 minutes.

Many scientists contend that our planet is experiencing its greatest mass extinction in 66 million years. At that time the dinosaurs vanished, along with between 60 and 80 percent of other animal species. Some small dinosaurs, however, already had evolved into the first birds. They made it through that extinction. So Igor’s eyes are also those of experience.

Igor and his fellow condors bring me back into the present. For months I have been keeping company with fossils. Trilobites. Ammonites. Triceratops. Titanotheres. All were victims of at least 12 mass extinctions, five of them immense, that our planet has endured since the fossil record of animals began about 800 million years ago.

Mass extinctions. The concept has hit science like a fireball during the 1980s. Paleontologists had long realized that occasionally large numbers of species disappeared simultaneously from the fossil record. Those disappearances often marked the close of geologic periods. Yet the causes behind those great dyings had remained obscure. The fossil record was too imprecise, too difficult to read, too pocked with missing pieces and contradictory clues.

All that is changing. Innovative geochemical techniques are coaxing subtle secrets from ancient rocks. Fossils are being reexamined. Computers are finding provocative patterns in the extinctions. In the process, the rules of evolution are being rewritten. And so is the four-billion-year history of life on the planet.

The excitement began in 1978 when a team from the University of California and Lawrence Berkeley Laboratory found a large enrichment of the element iridium in a pencil-thin, 66-million-year-old layer of rock from Gubbio, Italy. This iridium-rich clay lay right at the boundary between the Cretaceous period, when there were dinosaurs,
the free fliers, this ungainly bird whose scientific name is Gypaetus barbatus. He is called that. California condors are also known by the local Indian names. Pomo. For time beyond memory, throughout the West have regarded him as a god. His spirit, some say, in the thunderbird, whose flight is the flap of his wings, lightning in his eyes, as he perches in his pen at the eyes of extinction.

Condor number nine, was the first—and, zoo officials hope, to all the world might once again

reunion. Since the 1930s millions of California condors and preserve their home condors time—to sit, remote from extermination. Other creatures have not been so lucky. The dusky seaside sparrow disappeared in the time as many as a hundred years ago. The forests, among the most richly forested, are now destroyed. Ecologists can only speculate how many species have vanished, but of one thing they can be sure: the extinction of a species is not a new phenomenon. So Igor's eyes are also aimed back into the present. For though science has cataloged the victims of at least 12 mass extinctions on our planet has endured since the K-T boundary 66 million years ago. But science like a fireball during the nuclear tests, has occasionally large chunks of the fossil record. In the close of geologic periods. Yet the exact moment of the extinction of a species remains obscure. The fossil record, too pocked with missing Is being reassessed. New techniques are coaxing clues from extinction. In the present. The four...

In a team from the University of California, Berkeley say a large enrichment layer, 66-million-year-old layer on a rich clay layer right at the surface, when there were dinosaurs, and the Tertiary, when there were none. (Scientists nickname this transition the K-T boundary.)

Because iridium is rare on earth but common in meteorites, the Berkeley scientists—Walter and Luis Alvarez, Frank Asaro, and Helen Michel—proposed that earth had been hit by an asteroid ten kilometers (six miles) across. Wildly controversial at first, the proposal has since been backed up by abundant and convincing evidence from around the globe. Most scientists now concur that at least one great extraterrestrial object struck the planet around the time the dinosaurs died out.

With Alvarez I hike an Italian mountain road to inspect the Gubbio boundary clay. He digs out a chunk and hands it to me. "You are holding debris from the

(Continued on page 672)
Mass extinction: the causes... 

Through the study of fossil trilobites, below, and other creatures, scientists know that the story of life on earth has been punctuated by mass extinctions. But exactly how they occurred is a matter of unprecedented debate, sparked by the impact theory, lower left, and argued by scientists in fields as diverse as geophysics, astronomy, and paleontology.

"These are exciting times to be looking at extinction," says NAS geologist Bevan French, stating one of the few conclusions...
All scientists agree. At one end of the spectrum are those who believe mass extinctions are triggered by natural events such as the impact of a celestial body or by intense volcanic activity. At the other extreme, others argue that the process of mass extinction is gradual, brought on by environmental change wrought by rapid tectonic, oceanic, and climatic fluctuations. Many scientists say the truth lies somewhere in between, as a combination of earthly and extraterrestrial causes.

By plotting episodes of mass extinction throughout geologic time, some scientists have detected an interval of roughly 25 million years (orange vertical bar) between extinctions. This suggests a relatively predictable time scale for extinction—periodic comet showers, for example, triggered by the passing of a star or other celestial event. According to these calculations, life on earth is safe for another 12 million years.
The victims and survivors

Extinction has claimed 99 percent of all species that have ever lived—many of them victims of "background" extinction, the quiet and unheralded disappearance of species due to small-scale environmental changes. Others perished in one of earth's major mass extinctions (vertical bars denoted in the fossil record).

"During mass extinctions, the rules change," says paleontologist Jack Sepkoski, Jr., of the University of Chicago. It had been advantageous for certain species to become extinct, but in the mass extinctions, the species that had been dominant for millions of years were suddenly wiped out. But they vanished in the great Cretaceous extinction, while many smaller critters, including insects, spiders, and others, survived. In general, widespread extinctions seem to be triggered by environmental changes that are more subtle than the sudden and dramatic climate changes that are sometimes assumed to have caused them. But even these local and regional extinctions killed off a large number of species.

Horizontal color bars feature selected groups. The thickness of bar indicates the number of taxonomic families for each group. Red vertical lines denote mass extinctions.

Blue shading denotes Cambrian family diversity. Spawning on the Precambrian, the Cambrian was a time of extraordinary magnification in the Cambrian seas.

Pie slices, below, represent estimated percentages of marine animal species that have survived extinctions.

600 million years ago

Cambrian

Ordovician

Silurian

Devonian

Carboniferous

Permian

Mesozoic

Cenozoic

600 Million years ago

Early

Mesozoic

Late

Cenozoic

600 Million years ago

Assignment of animals to different periods is based on the fossil record, which, while imperfect, provides a rough guide to the ages of important events in the history of life.
impact,” he says. “In the first days
earth was hit, dust blanketed the entire world. It grew pitch-dark for one to three months. If the impact was on land, it probably got bitterly cold. If it hit at sea, the water vapor could have created a greenhouse effect, making things hot. Hot nitric acid would have rained out of the atmosphere—a life-threatening rain that would have dissolved the shells of organisms.”

That’s not all. A surprising discovery by Wendy Wolbach, a grad-
uate student at the University of Chicago, indicates that the world may
have turned even nastier, as it did last summer at Yellowstone
National Park.

A red sun shines like the eye of an angry god through the pall of blac-
owing smoke at Old Faithful. A rush of heat. A swirl of suffocating,
sooty air. Suddenly on the hillside behind the famous geyser the gate of hell burst open, and a fire storm races down the slope. A million
acres on fire. The worst conflagration to strike the vast Yellowstone ecosystem in history. An awesome, terrifying orgy of flame. Yet this
holocaust is insignificant compared with what Wolbach believes hap-
pened that day 66 million years ago when earth was hit. The entire
world caught fire.

Even as Yellowstone burns, Wolbach shows me her evidence in her
Chicago office—scanning electron microscope pictures of soot par-
and with the iridium layer from three widely separated sites—Spain, and New Zealand.

Wolbach's discovery stemmed from the curiosity of her research cosmochemist Edward Anders, about what kind of extraterrestrial object had struck the planet at the K-T boundary. A meteorite or asteroid belt? A comet? He suggested that Wolbach attempt to find carbon in the iridium layer. Carbon would have trapped cer- 

gases brought in by the impacting object. The isotopes of carbon might provide chemical signatures to identify the intruder.

It surprised Wolbach that an enormous enrichment of soot. "Yet the amount of soot we find," she says, "as much as 90 percent of the world's forests must have burned."

The impact of a ten-kilometer body would be equivalent to 

times the power of all the world's nuclear weapons, how could this have caused so disastrously across the globe?

If it hit in the ocean, the impact would have created a crater 
meters across," says Anders. "A huge plume would have 

the atmosphere aside. The fireball would have had a radius of 

thousand kilometers. Winds of hundreds of kilometers an hour 
have swept the planet for hours, drying trees like a giant hair 

two-thousand-degree rock vapor would have spread rapidly. It 

would have condensed to white-hot grains that could have started 

fires."

In addition, lightning discharges like those in a volcanic eruption 

have ignited windswept fires on all landmasses that marched far 

than those at Yellowstone.

UCH DOOMSDAY SCENARIOS strain our belief. And many scientists refuse to accept that such catastrophes have caused the great dyings.

"We don't need an impact," I have heard over and over 

from paleontologists. "We can explain mass extinctions with earthly causes.""

so they can. Falling sea levels. Ice ages. Collisions of conti-

nents. Volcanism. Climate changes. Altered ocean chemistry. The

itial mechanisms for mass death are many.

mater what causes them, mass extinctions do occur. They force 

perspective on the history of life.

mass extinctions change the rules of evolution," explains David 

Vassek of the University of Chicago, one of the leading extinction 

ists. "When one strikes, it's not necessarily the most fit that sur-

vives, but it's the most fortunate.

When their environment is disrupted, groups that had been healthy 

suddenly find themselves at a disadvantage. Other species that had

barely hanging on squeak through and inherit the earth.

The best example is mammals. Dinosaurs and mammals originated 
in the same place about 220 million years ago. But 

h million years dinosaurs ruled, while mammals stayed and 

ambilian hiding out in the underbrush. Mammals all basically 

littered alike—squirrelly or shrewish and no bigger than a badger—

the dinosaurs disappeared. Then they took over. Within ten million 

there were mammals of all shapes and life-styles: whales and 

mammals, carnivores and grazers. Mammals just couldn't do anything 

eating until the dinosaurs were out of the way."

CLUE to a killer's identity may remain in rugged central Quebec, where 

the Manicouagan crater was apparently blasted by a giant meteorite some 

210 million years ago. That roughly coincides with a mass extinction of marine species at the end of the Triassic period. Sky-darkening dust from the impact may have played a role.
LIVING FOSSILS, stromatolites were recently discovered by geologists of the Caribbean Marine Research Center in shallow waters of the eastern Bahamas. The mounds are composed of sticky mats of cyanobacteria (formerly known as blue-green algae) that cement sand and sediments. Appearing in rocks 3.5 billion years old...
stromatolites are the earliest known communities of life. They declined dramatically between 500 and 700 million years ago and survive today only in environments hostile to predators, such as this area swept by swift channel currents and in hypersaline waters in Western Australia, where a community was found three decades ago.
Mass extinctions thus promote new beginnings, new eras of experimentation. If earth’s state of life were not episodically wiped clean, how far might we have evolved beyond the primordial slime?

That slime surely suffered too. The first great extinction may have been a gas attack. As one microbiologist explains, “It was the worst case of pollution in earth’s history.”

What was this toxic waste, this obnoxious gas? Paradoxically, it was what today sustains all animal life: oxygen.

At one time earth’s oceans and atmosphere were virtually oxygen-free, or anaerobic. Carbon dioxide dominated the planet. Then, about three billion years ago, certain bacterial members of the primordial slime invented the kind of photosynthesis that releases oxygen as a waste product.

Oxygen is a reactive, aggressive gas. It shuts down or burns out organisms adapted to anaerobic life. So with oxygen, the new aerobic bacteria could crowd their way into a place in the sunlight and drive their competitors underground into extinction.

The waste built up. The oceans were oxygenated, then the skies.

No organism has so dominated the world as did those filamentous oxygen-producing microbes. Wherever seas were warm and not too deep, they built diverse bacterial communities—mountain-shaped mats of microorganisms. The silts of those mats, called stromatolites, resemble great reefs of cabbage-shaped mounds. Beds of layered stromatolites often several kilometers thick, swirled through rocks that were formed in shallow seas between 2.5 billion and 600 million years ago.

Then stromatolite populations crashed. Like the anaerobic life they displaced, stromatolites still exist but can be found only in isolated areas. What happened?

In a word, animals. Life began to feed on itself.

The appearance of animals heralded the adoption of a new survival strategy. Photosynthesis had enabled organisms to make their own food from carbon dioxide and water. The new strategy bypassed that step. Why make your own food? Why not eat some organism that has already done the work? Eating someone else takes energy, however. You have to graze or hunt. That requires a high-powered aerobic, or oxygen-burning, metabolism. As the advent of oxygen made grazing animals possible, it made sitting ducks of the stromatolite builders.

Animal life exploded across the planet at the start of the Cambrian period, around 570 million years ago. Perhaps oxygen levels crossed a threshold that enabled animals to make shells and experiment with increasingly complex tissue.
new eras of experimental life. Did the entire population start with a single species of bacteria?

The answer, of course, is no. For one thing, the Earth was not a single, united planet. Instead, it was a collection of islands, each with its own unique ecosystem. And each island had its own set of species, all adapted to their particular environment. So even if there were only one species of bacteria on Earth, that species would likely have evolved in different ways on different islands.

But we're getting ahead of ourselves. Let's start at the beginning. The Earth is estimated to be around 4.5 billion years old, and it's been quite active throughout this time. It's had its fair share of environmental changes, including the rise and fall of the oceans, the rise and fall of the ice ages, and the rise and fall of the dinosaurs.

Despite all of these changes, there have been times when life on Earth has been relatively simple. One such period occurred during the Ordovician period, around 480 million years ago. During this time, life on Earth was dominated by simple, single-celled organisms such as bacteria. There were no complex multicellular organisms, and there was no oxygen in the atmosphere.

However, as time passed, life on Earth began to evolve and diversify. New species emerged, and complex multicellular organisms began to appear. This diversification continued throughout the rest of the Paleozoic era, and eventually led to the emergence of the dinosaurs.

The dinosaurs, however, did not last forever. They died out around 65 million years ago, marking the end of the Cretaceous period. This was a time of great environmental change, with the rise of the greenhouse gases and the consequent warming of the planet. This, in turn, led to the loss of many species, including the dinosaurs themselves.

So, what happened to the dinosaurs? There are many theories, but the most widely accepted is that an asteroid collision was the cause. Whatever the cause, however, it marked the end of an era and led to the rise of the mammals. Today, mammals are the dominant species on Earth, and they continue to evolve and diversify, just as the dinosaurs did before them.
FORMED in the shallow sea that covered western North America 370 million years ago, limestone exposed in the Ancient Wall—a range in Canada’s Jasper National Park—may hold fossilized answers to what caused a mass dying of reef-building invertebrates during the late Devonian period.

“Maybe an extraterrestrial object splashed into the ocean,” says Palmer. “Perhaps, like today, the seas were strongly stratified—with oxygen-rich upper strata on top of cold, oxygen-poor deep water. If you threw that deep water onto these shallow shelves, you could have devastated the trilobites living there. Those organisms couldn’t stand even a few weeks of that.”

That scenario could explain the squarehead survival. Being primitive, they had been pushed to the cold, deep margins where no other creatures could make a living. They had adapted to just those conditions that exterminated their more advanced competitors.

After the Cambrian, trilobites never bounced back. Sophisticated new predators, suggests University of Washington biologist Peter Ward, made their life-style obsolete. Nautiloids, distant relatives of today’s chambered nautilus, combined massive jaws with the ability to swim swiftly across the seafloor. “As the airplane revolutionized warfare, the nautiloids created havoc for mudbound creatures,” says
“The early trilobites only looked ahead. The ones that survived looked up.”

Reef life—aborted early in the Cambrian—evolved anew in the Ordovician. Clams, starfish, and crinoids, lily-shaped animals that made gardens out of sea bottoms, also emerged. Then around 440 million years ago this increasingly diverse global ecosystem collapsed.

The most obvious villain in the massive Ordovician extinction was the planet’s own restlessness, the inner turmoil forever moving earth’s continents about. In the late Ordovician that turmoil drove a huge, ancient continent, Gondwana, over the South Pole. Immense glaciers developed, drawing their water from the oceans and chilling even the tropics. “The ice age literally drained the shallow seas,” says paleontologist Peter Sheehan of the Milwaukee Public Museum.

Reef life was especially hard hit during the Ordovician extinction. “Reefs are attractive but dangerous places to live,” says David Jablonski. “The web of interactions is so complicated that the entire community can crash if just a few of its members go. Reefs are always getting clobbered.”

EYE TO EYE with the Devonian disaster, Helmut Geldsetzer of the Canadian Geological Survey examines fossils exposed on an outcrop near the Lyell Icefield in British Columbia. He believes a sudden flooding of shallow seas by oxygen-poor water from the deep may have killed the reef builders. The cause, he suggests, “might be an asteroid impact.”
LAYERS OF CONTROVERSY surround a thin band of gray clay scrutinized by scientists on this seaside cliff in Zumaya, Spain. Found worldwide, the layer marks the boundary between the Cretaceous and Tertiary periods. Experts studying the clay seek
In 1980, a new scientist proposed that one of the reasons for the mass extinction of dinosaurs was an asteroid that struck the earth. This theory has since gained widespread acceptance. Scientists have found evidence of an impact—including high levels of iridium. Debate rages over the exact time of the collision, but there is general agreement that the impact caused the mass extinction. But few scientists deny that the impact was an extraordinary event, and that extraordinary events are recorded in that narrow layer of sediment.
catastrophists heatedly disagree, arguing that the event was about worldwide, and occurred in the midst of a long warm spell.

"At most we are dealing with 20,000 years—and maybe just a stormy night," says Willi Ziegler, director of the Senckenberg Museum in Frankfurt.

With Charles Sandberg of the U.S. Geological Survey, Ziegler studied fossils of abundant small eel-like animals known as conodonts. The shapes of conodonts changed often and distinctively enough during the Devonian that scientists can date rocks precisely with them. Particular conodont shapes in a rock indicate whether the rock formed in deep or shallow seas.

Ziegler and Sandberg’s conodont analysis indicates great swings of sea level around the time of the extinction. They see shallow-water conodonts suddenly appearing in deep-sea rocks. They argue that storms, and perhaps tsunamis, ravaged the planet, washing near-shore life out to sea. In Nevada, which was deepwater terrain, Sandberg has found huge boulders of coastal rocks that were apparently ripped seaward.

"We suspect this was caused by a comet shower or increasingly closer passes by an asteroid or field of asteroids," says Sandberg. "An asteroid’s gravity could raise great tides. It could increase the stress on marine life if sea levels were 30 meters, then dropped 60."

Wild thoughts? There are data from the Devonian to support speculation. The confusion grows worse with the next extinction, which terminated the Permian period about 240 million years ago.

The Permian was easily the greatest extinction of all time. Perhaps 96 percent of all species disappeared. No one claims strong evidence for an extraterrestrial extinction. The best guess today is that the planet itself did the killing.

The Permian extinction was the first to affect terrestrial life significantly. During previous extinctions most life was confined to the water. But by the end of the Permian, coal swamps proliferated, insects swarmed, and pig-size amphibians were roaming across earth’s warm surfaces. Creatures known as mammal-like reptiles dominated the land.

Mammal-like reptiles varied enormously. Early versions resembled lizards, but reconstructions of later species make me think of a deep-furred tank with a short tail. They may have had fur, and to specialists, their bone and teeth structure looks more mammalian than their simultaneously evolving reptilian cousins. For example, their limbs extended directly beneath their bodies, rather than to the sides, as the case with reptiles.

Even as the mammal-like reptiles were evolving during the Permian, the forces of plate tectonics were forging the supercontinent Pangaea, joining all the planet’s continents into a single colossal landmass. But one continent the amount of shallow offshore water—among the richest habitats on the planet—shrank drastically. Also, Pangaea encroached on both poles, probably triggering a series of crippling

EVIDENCE of impact, this tiny spherule collected from the K-T boundary layer at Zamaya is thought to be a melted fragment of the object that struck the earth 66 million years ago. The spherule, here magnified 5,000 times, contains platinum in the high concentration present in meteorites but not normally found on earth.

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was abrupt, not gradual.

In the week before the extinction, Ziegler notes, if you went to shallow-water areas, you would have seen a change in marine life. Instead of conodonts, which are small, round teeth that lived in the depths and were sensitive to the least change in their environment, you would have seen more shallow-water species.

The reason: shallow-water species turned over every month or so, while the conodonts lived for 20 years or more. So, a few months before the extinction, the shallow-water species were gone, replaced by the conodonts. This suggests a catastrophic event such as the impact of a comet or asteroid, Ziegler says.

A December 1989 study of the extinction by an astonomer, James Vlacich, of the University of Minnesota, supported this idea. Vlacich found that the total sunlight striking the earth 65 million years ago had been reduced by 15 to 25 percent. This could have been produced by a comet impact, he said.

Another line of evidence came from the impact theory was the finding of shocked quartz grains. These are grains that have been shocked by a high-velocity impact. They can be found in the rocks of the K-T layer, the boundary between the Cretaceous and Tertiary periods.

GEO-DETECTIVE Glen Izett of USGS was skeptical about the impact theory. Then his light-polarizing microscope revealed quartz grains in samples of the K-T layer (above) with the type of fractures caused by nuclear explosions or meteorite impacts. Judging from the size and abundance of “shocked” quartz grains he has found in the western U.S., Izett believes the impact occurred there.

In both hemispheres. According to paleontologist Bob Sloan of the University of Minnesota, sea levels bobbed up and down by 200 feet, coastlines advanced and retreated 1,900 kilometers (1,200 miles). Even tropical seas would have been chilled. On land climate was progressively drier, the winters Siberian.

The mammal-like reptiles suffered at least six distinct mass extinctions during the last eight million years of the Permian, says Sloan, noting that the great die-offs may occur in pulses. Those pulses reflect the Permian’s strong climatic swings. The die-offs illustrate paradoxically, extinctions can benefit life.

Look at what survived each pulse,” says Sloan. “The survivors were always those that appear to be more warm-blooded and thus adapted better with cold climates. They also tended to have more complicated jaws and teeth, as well as more efficient respiratory systems.”

Moreover, the survivors were small, establishing a pattern for subsequent terrestrial extinctions. As Sloan says, “The surest route to extinction.
Effects of an ancient cataclysm

The scenario is straight out of a science-fiction movie: Giant meteorite strikes earth, setting the planet afire. Volcanoes erupt, tsunamis crash into the continents. The sky grows dark for months, perhaps years. Unable to cope with the catastrophic changes in climate, countless species are wiped off the face of the planet.

Yet that is the apocalyptic scene scientists suggest, as evidence grows that comets or meteorites may indeed be agents of mass destruction on earth.

In the moments following the impact of an object ten kilometers in diameter, experts believe, a blast wave similar to that of a nuclear explosion would destroy everything within several hundred kilometers, its intense heat and winds combining to set wildfires, perhaps even a global inferno. If the impact occurred on land, earthquake would rock the continent for days. If at sea, huge tsunamis could destroy coastal habitats across the globe. Other immediate effects would include a horizontal "base surge" of melted and pulverized material and a plume of vaporized water and/or rock ejected into the stratosphere above the impact crater—the fine particles eventually darkening skies around the world.

Scientists are debating the long-term effects of such an impact. Most agree that an acidic rain would ensue. Some believe a global dust cloud would trigger an age of darkness and cold. Others see a sharp rise in atmospheric CO₂, a greenhouse effect—particulate matter from the impact would block sunlight, lowering temperatures worldwide.

National Geographic, June 15, 1999
Global Effects

Global darkness

Acid rain

Greenhouse effect

LONG-TERM, GLOBAL EFFECTS (MONTHS TO YEARS)

Debris from the K-T layer from around the world, Wolbach found high levels of soot, suggesting a global wildfire started by an impact. Magnified on her screen is soot found in strata similar to those she holds from New Zealand. The light-colored rock at bottom is from the Cretaceous. A dark layer marks the K-T boundary, when 75 percent of animal species became extinct.
extinction is to be large." Big creatures need more food and have trouble finding hideouts.

One squat creature whose ancestors made it through the end of the Permian was a tusked herbivore called *Lystrosaurus*. About as big as E. T., *Lystrosaurus* exploded across Pangaea after the Permian largely because there wasn't much left big enough to eat it.

In the ensuing Triassic period evolution soon produced not only large new mammal-like reptiles but also waves of new experimenters. Marine monsters called ichthyosaurs and plesiosaurs roamed the seas, crocodiles roamed the swamps. Flying pterosaurs took to the skies.

The first dinosaurs also appeared in this period. Extremely fast and small, they were two-legged, probably resembling big pheasants on the run. Their posture freed their forelegs to be used as hands for grasping.

If not warm-blooded, most dinosaurs had evolved high metabolic rates perhaps were covered with down, later, feathers. Nevertheless, for all their superior performance, dinosaurs could not, by themselves, replace the mammal-like reptiles.

AT THE CLOSE of the Triassic period, about 200 million years ago, the dinosaurs have gotten a little help from the cosmos. In the wilds of central Quebec sits the Manicouagan crater, half the size of Connecticut. The only radiometric dating of remote Manicouagan puts the impact several million years before the end of the Triassic. However, paleontologist Paul Olsen of Columbia University’s Lamont-Doherty Geological Observatory suspects that the dates are wrong and the Manicouagan impact is the fingerprint of a global mass extinctions from space.

“The fireball alone from an impact that size would have scorched everything down to New Jersey," he says. It thus could have created the kind of global havoc suspected at the K-T boundary.

Whether or not they had cosmic good fortune, the dinosaurs took charge of the land with the advent of the next period, the Jurassic. During the Jurassic's 60 million years, the great reptiles developed by far much larger size. The gargantuan *Brontosaurus* and related creatures roamed river plains, browsing tall conifer trees. So did the armored tractor-size *Stegosaurus*, although it might have had to stand on its hind legs to nibble the branches. It had to stay ever alert for the meat-eating *Allosaurus*.

These monsters vanished, along with many smaller dinosaurs and marine creatures, when a profound but mysterious crisis struck at the end of the Jurassic. A new generation of low-browsing, beaked dinosaurs emerged. What made them the evolutionary victors? Was the...
habitat change? Why was life in the oceans also hard hit? The mass killer left almost no clues.

Dinosaurs life rebounded vigorously during the long warm eons of the Cretaceous period. Then, about 90 million years ago, another pulse of extinctions struck both land and sea. The only spike of iridium has recently been reported for this mid-Cretaceous extinction, implying impacts from space. Because other spikes have not been uncovered for this boundary, the significance of the spike is being challenged. But is may be a more surprising suspect of extinction—flowers.

At this time blooming and fruiting plants, known as angiosperms, took off across the land. By attracting animals to spread their pollen seeds, the angiosperms colonized the world over to flowers. Dino-mammals overgrazing threatened many growing plants with extinction—too much for the angiosperms. Their reproductive superiority helped flowering plants compete with the munching of oblivion.

In turn, this contagion of angiosperms must have had an enormous impact on the dinosaurs' diets. Could Cretaceous extinction have linked to their mid-Cretaceous extinction?

Certainly new dinosaurs evolved in the aftermath. The late Cretaceous saw rhinoceros dinosaurs prowling the swamps and forests. On the more open plains, especially in western North America, great herds of rhino-like ceratops and their relatives fed on the new vegetation. Back then a tiger across the Dakotas would have resembled a saurian with the Serengeti Plain. The lion of that world was the monstrous Tyrannosaurus rex.

In all, at least 30 genera of dinosaurs—perhaps a hundred species—habit the planet during the final ten million years of the Cretaceous. Some specialists argue that most persisted right up to the K/T boundary. Others, as David Lamont-Doherty and Jack Sepkoski of the University of Chicago, believe that global cooling explains most mass extinctions. He holds a Spondylus, a tropical bivalve that died out some 3 million years ago. At the other end of the spectrum, paleontologist Steven Stanley of Johns Hopkins University (above) believes that global cooling explains most mass extinctions. He holds a Spondylus, a tropical bivalve that died out some 3 million years ago.

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detail—with iridium and an abundance of fossils—the dying of the dinosaurs.

On this July morning the bleak buttes are speckled by the cut T-shirts of scientists and volunteers sent by the Milwaukee Public Museum. Hammering and chiseling under a blazing badland sun, Claudia Berghaus, Joan Mathys, and Carol Moertl extricate from the butte, near the K-T boundary, working on scraps of a Triceratops front leg bone. Doug Stephenson is perched high in the butte, near the K-T boundary, working on scraps of a scapula.

"I can't get over it," says Jay Warner, who is usually an engineer. "Back in Milwaukee I was worried I wouldn't find a single bone. I found a piece of a turtle in my first five minutes, a dinosaur in ten.

"We want to know what the pattern of diversity was," explains the museum project's coordinator, Peter Sheehan. "It has not been adequately shown that dinosaurs already were dying out before the impact. We're trying to eliminate one of the two possibilities—the whimper or the bang. A gradual pattern of decline is not what you expect if an asteroid killed them."

Sheehan contends that past estimates of dinosaur diversity are
The better-known North American fossil sites have been mined more thoroughly than other spots. Dale Russell of the National Museum of Canada says dinosaur diversity in North America did not significantly increase before the boundary. In central Asia, another fossil-rich area, it increased, while much of the world remains unexplored.

Past, fossil hunters usually collected only museum-quality specimens. They ignored the scraps, which may be the most valid indicators of the real abundance of late Cretaceous life.

The scrap that creates the most excitement on this day is not dinosaurian, nor even reptilian. "We've got a mammal," announces museum paleontologist Diane Gabriel, bending over her sliver of a discovery, a jawbone from a marsupial. "It was probably slightly larger than a chihuahua. That means it was a giant for its time."

Mammals are rare in these late Cretaceous rocks, but in the eyes of the Minnesota paleontologist Bob Sloan they are far from insignificant. Sloan believes that 200,000 years before the K-T boundary a receding sea level had created a land bridge between North America and the long-isolated Asian continent. A plague of little Asian mammals invaded North America and began eating the same flowering plants that most dinosaurs ate.

"The mammals ate much less food per animal," says Sloan. "But there were so many of them. They ate the last of the dinosaurs out of house and home." Others suggest the dinosaurs' nemesis was a climate-induced change in vegetation.

In fact, the dinosaurs and their huge flying cousins, the pterosaurs, were among the few land-based animals to go extinct at the end of the Cretaceous. Turtles, crocodiles, many lizards, and most mammals made it through, perhaps because they did not eat much and were small enough to find refuges.

The cruelest K-T extinctions struck the seas. Most plankton, the primary food source, died out—understandable if months of darkness or acidic rain followed an impact. All large marine reptiles also vanished, as did most denizens of the seafloor. Rudists, huge coral-like clams whose shells built Cretaceous reefs, were obliterated. Ammonoids—lovely, coiled survivors of many past extinctions—died out completely.

Not all these creatures disappear from the fossil record right at the
K-T boundary. Some vanish earlier in steps. Thus other scientists argue that the K-T impact was not the cause of the dying. “Extinc
tions were decaying for at least two million years before the impact,” explains paleobiologist Steven Stanley of Johns Hopkins University.

Stanley, a prominent theorist, sees long-term cooling as the explanation. Yet there is no obvious reason for such cooling. The next ice age occurred tens of millions of years away. Massive volcanic eruptions may have dropped global temperatures temporarily by injecting particles into the atmosp

phere that blocked sunlight. Indeed, one of the greatest outpourings of lava the world has known occurred at the K-T boundary. A great basalt flow buried the Deccan region of India. However, many volcanologists doubt that the relatively calm nature of lava eruptions would propel much debris into the upper atmosphere.

Whatever cooled the planet, Stanley contends that the impact at the K-T boundary probably was but a final insult to an already overstressed global ecosystem.

As I was told by another paleontologist: “Things got bad, then they got worse.”

Impact enthusiasts have recently come up with a way to explain multiple stages of K-T extinctions. Earth, they argue, was hit not by one great object but rather by a shower of comets that bombarded the planet over several million years.

Erle Kauffman of the University of Colorado finds evidence for this disarray in ocean chemistry beginning two million years before the
Those disruptions, he argues, were created when comets hit the seas, generating tsunamis and overturns of deep anoxic or stagnant waters like those suggested for earlier extinctions. Those oceans could have created global climate crises far worse than El Niños experience today. The final terminating impact, says Kaufmann, probably occurred on land, where it produced fire storms, soot, and a wall of dust.

A major question surrounds the final impact. Where’s the crater? It is not always obvious.

The largest impact and the largest crater in the past hundred million years occurred at the same time as the eruption of lava,” observes Michael Rampino of New York University. “That’s quite a coincidence. He and others suspect that the impact struck India, thereby creating the Deccan basaltic lava flows. If Rampino is right, the K-T crater is buried beneath the basalt.

Consider the quiet farm town of Manson, Iowa. It sits over the center of a kilometer-wide crater that glaciers and debris formed during the last ice age. Today the only striking feature is an inner pit. The 32-kilometer hole is just an inner pit.

Some scientists agree that 32 kilometers is too large to create the envisioned by impact enthusiasts. In fact, some suspect Manson’s crater is larger. The 32-kilometer hole is not a crater, but the scarred sea floor. It could have been buried by sediments or recycled into the planet’s innards by plate tectonics.

Perhaps more controversial than the impact hypothesis itself is the notion that such showers occur regularly. Jack Sepkoski and David Raup of the University of Chicago have combed a century and a half of fossil record keeping and found a pattern. They see peaks of extinction about every 26 million years. Such regularity implies a cosmic driver to extinctions. No known earthly mechanism keeps such good time.

Many scientists dispute Raup and Sepkoski’s statistical methods; many concur, seeking astrophysical explanations. The most obvious source for the calamities would be the dense cloud of comets that astronomers believe surrounds the outer solar system. Something could periodically unseat that cloud, flinging a battalion of comets toward the inner planets over several million years.

Three mechanisms have been proposed. A dense, dark companion to our sun — a planet that never materialized — might periodically set its gravitational pendulum swinging. Another is a supernova or a white dwarf star that periodically passes near Earth. That would heat the Earth’s surface and oceans, causing millions of extinctions.

Terror of the trilobites, Anomalocaris (above, at center) did not last long, but many a trilobite shows wounds attributed to the predator. It was extinct by the end of the Cambrian, whereas trilobites hung on until the Permian mass extinction. The fossil of a Jurassic fish covered with armor-like scales is removed from a West German quarry (facing page).

Jonathan Blair, D. L. Bruten, A. Jensen; photographed at Paleontological Museum, Oslo, Norway (above).
star orbiting our sun would toss out comets as it passed through cloud. So might an unknown, tenth planet. Thirdly, our solar system moves periodically up and down through the star-dense spiral of Milky Way galaxy. Perhaps our comet envelope is perturbed each time we pass through that spiral arm.

Astrophysicists find dynamical problems with all three mechanisms. Many argue that the showers strike randomly, not regularly. Of course, see a frequency not of 26 but of about 30 million years.

Both spacings fit the next era of extinctions, which hit between 1 and 40 million years ago: Those dyings eliminated herds of rhino-like mammals and many sea creatures. Although iridium spikes correlate with some of these die-offs, gradualists argue that a well-documented dying of the seas did the killing.

Advocates of the 26-million-year period point to a mild extinction around 14 million years ago as evidence for the most recent bombardment. That places us today safely between showers. Those favoring million-year or random spacing are less sanguine.

Michael Rampino points to three large craters—Bosumtwi in Ghana,
in diameter) and two in the Soviet Union, Elgygytgyn (9 meters) and Zhamanshin (13 kilometers)—that were created in the past 3.5 million years.

"Widespread extinctions could still be in a shower," says Rampino. "Halley's comet is part of it. We aren't out of the woods yet."

Rampino notes that three mechanisms for impacts occur regularly. Others occur irregularly. Others occur irregularly. Others occur irregularly. Others occur irregularly.

"About 2.3 million years ago there was an abrupt shift in climate," notes geologist Frank Kyte, leader of the University of California at Los Angeles research team that discovered evidence of the impact. "Huge continental ice sheets developed in the Northern Hemisphere."

Kyte notes that the climate had been deteriorating before this, our most recent ice age, set in. But he speculates that the injection of water vapor into the stratosphere could have formed a global cloud cover that reflected heat off the top of the atmosphere.

"No one would argue that impacts alone cause ice ages," adds Mike Rampino. "But might they push the climate into a new state?"

Although hit between 35 and 25 million years ago, none of the thousands of rhino-like beaked whale species has been documented since.

A mild extinction event may have occurred within the past 300,000 years. Those favoring 300,000 specify that the last mass extinction occurred 25 million years ago. That is when mammals became the dominant life form on the planet. That is when mammals became the dominant life form on the planet.

The extinctions, however, were widespread—within five hundred to a thousand years—that many scientists expect an alternate—or at least assistant—villain in this extinction: Homo sapiens. Man the hunter emerged from the Ice Age with lethal hunting technologies—snare traps, and sharp-pointed weapons. Today the impact of human technology on the biosphere worsens. It exterminates not just the big creatures but the tiny. Man has become an asteroid. A very big one.

It is easy to blame today's frightful extinctions on habitat destruction and development in the developing countries. To be sure, the crisis is acute in Brazil and Madagascar and the Philippines, where rapidly expanding populations...
Economic development can erase a forest in weeks. "Sing their inheritance," says botanist S. H. Sohmer of the R. H. S. Heyburn in Honolulu. Just back from the Philippines, the local biologists bolster national awareness of the picture paints a dismal picture.

A group I study, 42 percent of the species reported in been collected since," he says. "The leveled forests are by an aggressive plant called cogongrass. If the logging burn agriculture don't stop soon, we'll wind up with en- dered by it. Conceivably this archipelago, which once world's richest biotas, will end up with only a handful of the wealthier countries to decry and then ignore these. But we have only to ask who buys the timber or beef is produced. Or who generates the acid rain that is wiping England's sugar maples or or's Black Forest.

States can look at Hawaii, us regard as paradise but us consider the endangered species of the world. Though occu- 0.2 percent of the nation's nial wall contains 27 percent of 1 birds and plants. Seventy- of those U. S. species that become extinct did so on

LAKAI SWAMP on the island of a male 'a'a'a'a'a sings his holy song alone.

The best songster in the " says state aviculturist Fern "His call is unforgettable, of the old Hawaiians."

In three years the mating calls we gone unheard. For he is a species, the end of the line. Not only a species," says its entire family—all the will be gone.

na, in Honolulu's Bishop Mu- children file past the celebrated yellow feather cape of King as I. The cape was assembled from the plumage of the lost in the late 18th century.

The feathers from 80,000 birds to make this cloak," says Hawaiian birds were flightless. Before humans the islands mammalian predators, and wings grew less useful. Thus rats brought rats and dogs, native birds and eggs were easy the goats, pigs, and cattle ravaged avian habitats. Humans forests.

Lava tube on the island of Maui ornithologists Storrs Olson James of the Smithsonian Institution excavate soils depos- the past 8,000 years. A dark layer high in the soil strata

PRIZED for its plumage, the Hawaiian 'a'a'a'a (top) was overhunted to adorn cloaks like one worn by chief Kamehameha (facing page). After studying the fossil record in Maui's lava tubes, Helen James of the Smithsonian Institution (above) rates predators introduced by Polynesians—pigs, dogs, and rats—as more deadly agents of extinction.
contains charcoal, which has been dated as being 825 years old. We think the charcoal correlates to the burning of the forests for agriculture,” says James. “We see bird bones below the charcoal and Polynesian rat bones above. Later we get black rats and house mice, announcing the arrival of the Europeans.”

New diseases arrived too. An avian pox, imported in 1964 on a pheasant from Nepal, most likely brought one of Hawai'i's native birds, the 'alala, or Hawaiian crow, to the twilight of extinction.

At the Olinda Endangered Species Captive Breeding Facility on Maui nine of the last fifteen known Hawaiian crows await the season in their pens. Overnight someone has placed an offering of black basaltic stone wrapped in a large leaf—beneath a statue of a Hawaiian salamander god that stands on the lawn of the station.

“The offerings began when the crows were brought here in 1976,” says Fern Duvall, who is in charge of the facility. “We must assume that someone is trying to help the crows reproduce.

“Actually, the Hawaiians did not think the ‘alala was a bird,” he continues. “It behaves in remarkable ways. It feeds with its beak like a parrot. It shrieks, growls, and moans. It makes noises more like a tiger. When the feather hunters heard it in the fog-bound forest, they thought it was a spirit. If you killed an ‘alala, you paid with your life.”

This season’s courtship is beginning. In one pen a male, named Keawe, and a female, Mana, are carrying out the building of a nest using their beaks. They display their love displays. Their efforts are doomed: Disease has left Mana sterile. Ever, the mating ritual stimulates useful behaviors. Keawe’s semen could later fertilize other females. Mana could sit on a nest abandoned by another female.

The three other pairs of crows offer varying degrees of hope for building a captive population. Even so, the outlook for the ‘alala is bleak. There is simply no safe place for them in the wild at this point.

I AM ANGRY as I rest from a hike on the slopes of the volcano Haleakala. In Hawaiian prehistory I would have been sitting in a diverse forest rather than this overgrazed scrubland dotted by prickly plants that cattle won’t eat. Almost nothing, from the peacock that preened minutes earlier in my path to the cabinet butterfly that just now alighted on my arm, is native. Is this the island slope, where only the rats and the pigs and the cacti, the microcosm of our future?

Other questions, fed by my fieldwork, arise. Hasn’t this happened before—diversity suddenly becoming paucity—and each time did life recover to reach new heights of evolutionary creativity? In the picture is it really so terrible, what’s happening today? Life will go on. No matter how bad we make things, some organisms will cope, survive, then flourish. Isn’t that the lesson of mass extinctions? What is different about this one?

We are the difference. For the first time since life on earth began four billion years ago, a living organism can begin to understand what is happening to this planet. We can see that the health of species is interconnected, that if we let too many disappear, we will go too. If the first time, a living organism can consciously do something to halt a mass extinction. Perhaps most important, for the first time a living creature can gaze out across the species of the earth and say: This is beautiful. I care. I will not let it go.

National Geographic, June 1
that 825 years old.

The forests for ages have been divided and all the charcoal and if the forests are cut, animals and house mice
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is reported in 1964 with the other 80% of Hawaii’s most

darkest period. The presence of extinction

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s at the Spring, a statue of a Hawaiian

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