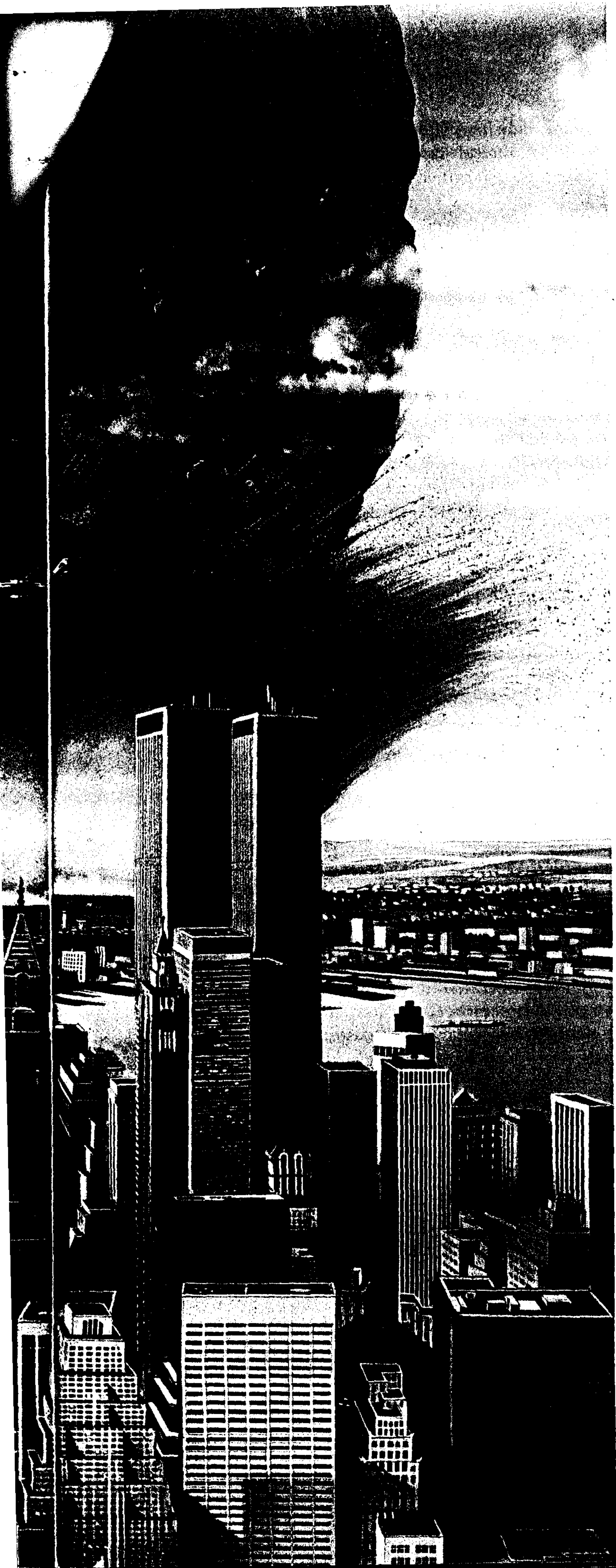


By James Trefil

Stop to consider the stones that fall from the sky

More often than we once thought, huge comets and asteroids strike Earth with catastrophic effect—a few months ago, one barely missed us

Astronomers saw it coming, but there was nothing anyone could do. Millions of miles away, a comet was streaking toward the Sun at 100,000 miles per hour. A dirty snowball 30 miles across, it was making its first pass through the Solar System. Against all odds, it was on a collision course with Earth.

All too soon, the dread moment came. The comet brushed aside the first tenuous wisps of atmosphere; its outer skin heated as the air thickened. So fast was it moving, however, that it scarcely slowed during the second or two it took to reach the ground.

Its tremendous momentum carried it several miles down into the rock. All of the energy accumulated during the thousands of years it had been falling toward the Sun was released as heat. With an energy equivalent to 100,000 times the entire nuclear arsenal of the human race, the comet exploded. Rock in the immediate vicinity was vaporized; that farther away was pulverized. A plume of debris was flung up at five times the speed of sound, heating the air over an area the size of Africa to 3,100 degrees F. Nitrogen and

Asked to show what would happen if a comet nucleus 30 miles in diameter hit Earth, the artist brought it down in northern New Jersey. This is the moment of impact. Everything visible, including the buildings of lower Manhattan in foregound, would be vaporized; plume of ejected material would soon cover globe.


Early version of aerial combat included cannon that bombarded Earth with meteors, in 1628 woodcut.

oxygen in the atmosphere combined to form a red smog of nitrogen oxides. In a few seconds a crater a hundred miles across had been blasted out.

Pulverized rock and dust continued out of the atmosphere and into space. There most of it was slowed by Earth's gravity and started to fall back in, creating the equivalent of an inch-thick layer of dust on top of the atmosphere all around the planet, blocking almost all the sunlight.

During the darkness, which lasted three months, the smog spread out from the impact site, blocking still more light. Within a year it had spread over the entire globe. Slowly the noxious cloud combined with water vapor to form nitric acid. The skies dripped acid rain, acid as strong as that in a car battery.

All this may sound like science fiction, but Ronald Prinn, professor of meteorology at the Massachusetts Institute of Technology, takes it very seriously. His computers spin out scenarios of what would happen to Earth if a giant comet or asteroid did hit. The doomsday story I've just told is the work of Prinn and his colleague Bruce Fegley; a worst-case scenario, to be sure, but a realistic one nevertheless. They suggest that scientists consider their acid rain theory as a possible cause for the mass extinction that took place 66 million years ago. "My problem isn't so much in killing things off," says Prinn, "but in finding ways for things to survive."

Prinn and Fegley are not dabbling in idle speculation. The kind of event they describe *can* happen; it has happened in the geologically recent past and it will happen again. Only in recent years have astronomers realized how often Earth is still being hit, and how certain is the probability that it will be hit again.

We have known for a long time that our planet is constantly being pelted with small particles, mostly the size of grains of sand and pebbles. We know that sometimes the projectiles are larger—the size of golf balls, bread boxes, even office desks. Twenty tons a day come filtering down through the atmosphere, the detritus of interplanetary space.

It has taken longer to realize that the heavy bombardment we associate with the early days of the Solar System, the barrage that left the surfaces of the Moon and Mercury so pocked, is still going on. But just last March an asteroid as much as a half-mile across, millions of tons of rock moving at 44,000 mph, shot by Earth at only twice the distance of the Moon.

If it had hit, according to Bevan French at NASA, the impact would have been equivalent to the explosion of 20,000 one-megaton hydrogen bombs, leaving a crater five to ten miles across and perhaps a mile deep. Known only as 1989FC, the asteroid orbits the Sun once a year in a regular elliptical orbit; it will be back. "Sooner or later," said its discoverer, Henry Holt of Northern Arizona University, "it will be drastically affected by Earth's gravitational well: either it will hit us, or Earth will sling it away."

No one saw it go by. Holt discovered the cosmic near miss when he looked at photographs (p. 92) taken March 31 with an 18-inch telescope on Palomar Mountain. Working backward in time after calculating the orbit, astronomers realized that 1989FC had crossed Earth's orbit on March 23. If Earth had happened to be at that point in its orbit on that day, the results would have been catastrophic. As it was, the asteroid missed us by only six hours.

We probably will not see the one with our name on it in any event. Asteroid hunters find their faint, fast-moving quarry by comparing photographs taken of the same sky field about 45 minutes apart. The asteroid stands out because it has moved in that time. But Carolyn Shoemaker (she and her husband, Eugene, make up one of the premier asteroid-hunting teams in this country) points out that one coming straight at us would not appear to move when the photographs were compared. It would most likely look like just another star, and would be ignored.

A half-dozen events in this century alone have made the astronomers nervous. Twenty-one years ago the asteroid Icarus sailed so close by Earth that, for the first time, scientists began to think seriously about sending up a rocket armed with thermonuclear weapons to nudge such an object into a new orbit. In 1937 Hermes missed us by about as much as 1989FC did. In 1932 Karl Reinmuth of Heidelberg discovered Apollo, the

A physicist at George Mason University, James Trefil works with paleontologists at the University of Chicago and hunts dinosaur fossils in Montana.

first Earth-crossing asteroid to be recognized as such and the one that gives its name to the whole family. And it was back in 1908 that an object the size of a small office building—probably an old comet—exploded near the Stony Tunguska River in Siberia with the force of 12 megatons of TNT.

Gene Shoemaker estimates that there are 1,500 asteroids and comets big enough to be measured in kilometers that could collide with Earth someday. Objects the size of mountains, moving at speeds measured in miles per second, are out there, crossing and recrossing Earth's orbit. Sooner or later, one of them and Earth will arrive at the same place at the same time.

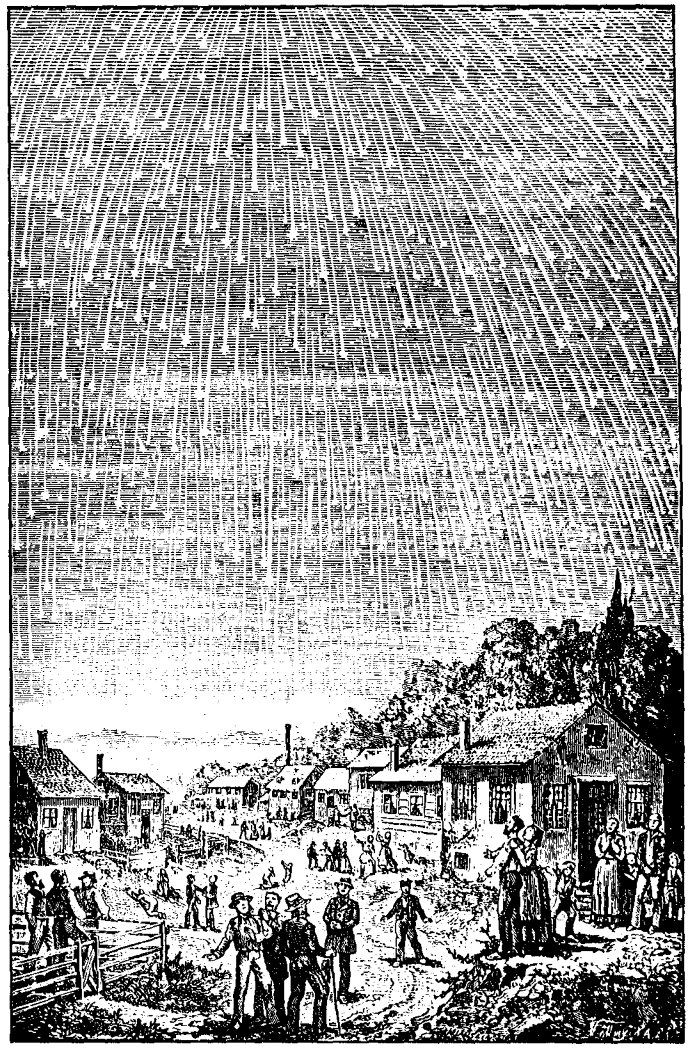
Would two Yankee professors lie about it?

Meteors—those momentary streaks of light we see in the sky—have always been visible to humans. Today we know that each streak marks the death by incineration of a piece of rock usually no larger than a pea, a tiny cousin of Prinn's doomsday comet. But educated people did not always look at meteors this way. In 1718 Edmund Halley, the Astronomer Royal of Britain and no mean cometeer himself, explained a bright meteor that was seen over much of Europe as the ignition of certain "inflammable sulphereous Vapours" in the atmosphere. Even Thomas Jefferson was not immune to a bias against objects coming from space. Told that two professors from Yale had confirmed such an event, he is supposed to have remarked, "I would prefer to believe that two Yankee professors would lie rather than that stones could fall from heaven."

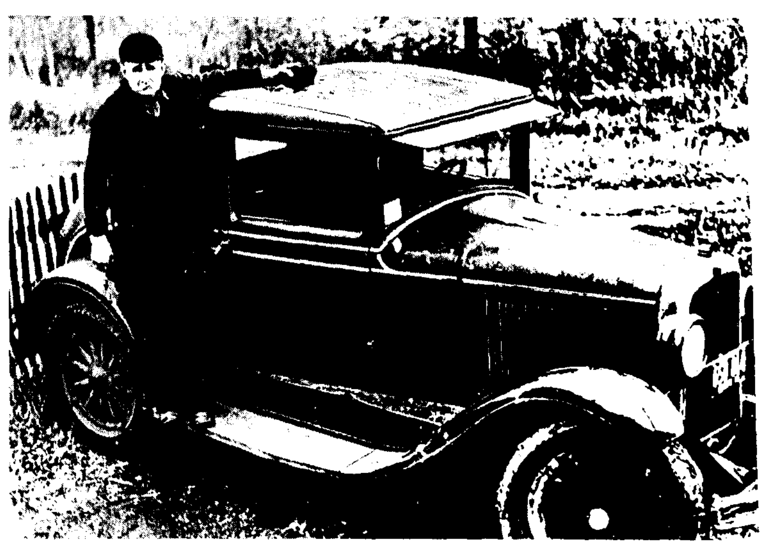
What seemed to be difficult for these men and their colleagues to accept was that the streak of light in the sky (a meteor) could turn into a stone on the ground (a meteorite). I would guess that this attitude was a holdover from the old idea that Earth was somehow special. To admit that rocks fell from the sky was to admit that Earth and the rest of the Universe formed a seamless web—that our planet is neither isolated nor special.

Two developments led to the acceptance of meteorites. One was the birth of modern chemistry in the late 18th century, and the consequent ability to analyze rocks that are supposed to have fallen from the sky and see whether they are different from their neighbors. The other was a spectacular and well-documented meteorite fall near the town of L'Aigle, in northern France, on April 26, 1803. A commission of the French Academy of Sciences quickly traveled to the site and confirmed that the stones were not terrestrial in origin. With this "smoking gun," the artificial division between Earth and the rest of the Solar System vanished.

During the 19th and early 20th centuries, meteorites were not only accepted but hunting them became a



Meteors sometimes fall in enormous numbers, as in this rendition of the night of November 13, 1833.



Ed McCain holds the meteorite that crashed through his garage roof and car in Benld, Illinois, in 1938.

Trees were leveled over 750 square miles when comet exploded above Siberia's Tunguska River in 1908.

A ring lake 40 miles in diameter marks the spot in Quebec where Earth was struck 212 million years ago.

scientific cottage industry (SMITHSONIAN, May 1980). The meteorite, with its tortured, burned skin, became a standard exhibit in the world's museums. While growing up in Chicago, I remember being tremendously impressed by a display showing a meteorite that had fallen through a garage roof, puncturing the top of a car and coming to rest in the seat. All the relevant pieces—the garage roof, the car roof, the seat and the stone—were there.

But for all this acceptance of the impact of extraterrestrial bodies on our planet, a curious kind of tunnel vision kept scientists' attention focused on small objects. There seemed to be no thought that if small bodies strike the Earth fairly often, the big ones—the sort that Ronald Prinn and Bruce Fegley's computer envisions—would hit occasionally, as well. And this meant that no one went out to look for the large craters that would have been left behind.

In 1891, for example, geologists first visited a place called Coon Butte (now better known as Barringer Crater or Meteor Crater) in Arizona, the archetype of the remains of an impact (p. 93). They concluded that the crater was caused by a steam explosion within the Earth—analogous to the bubbles that form when you heat thick oatmeal on a stove.

Throughout the first half of this century, geologists expended extraordinary efforts trying to explain away evidence that craters on Earth had been formed by impacts of extraterrestrial bodies. Campo del Cielo (Field of the Sky) in the Argentine pampas is a place where pieces of a meteorite created several holes in the

Harvey Harlow Nininger used a metal detector to find meteorite fragments.

Curator emeritus Edward Henderson (now 90) found these meteorites, today in the Smithsonian collection, in Australia's Wolf Creek Crater.

ground, some of them almost a hundred feet across, with the fragments of iron still lying at the bottom. A geologist studied the site and announced that prehistoric people had dug the pits to bury the iron!

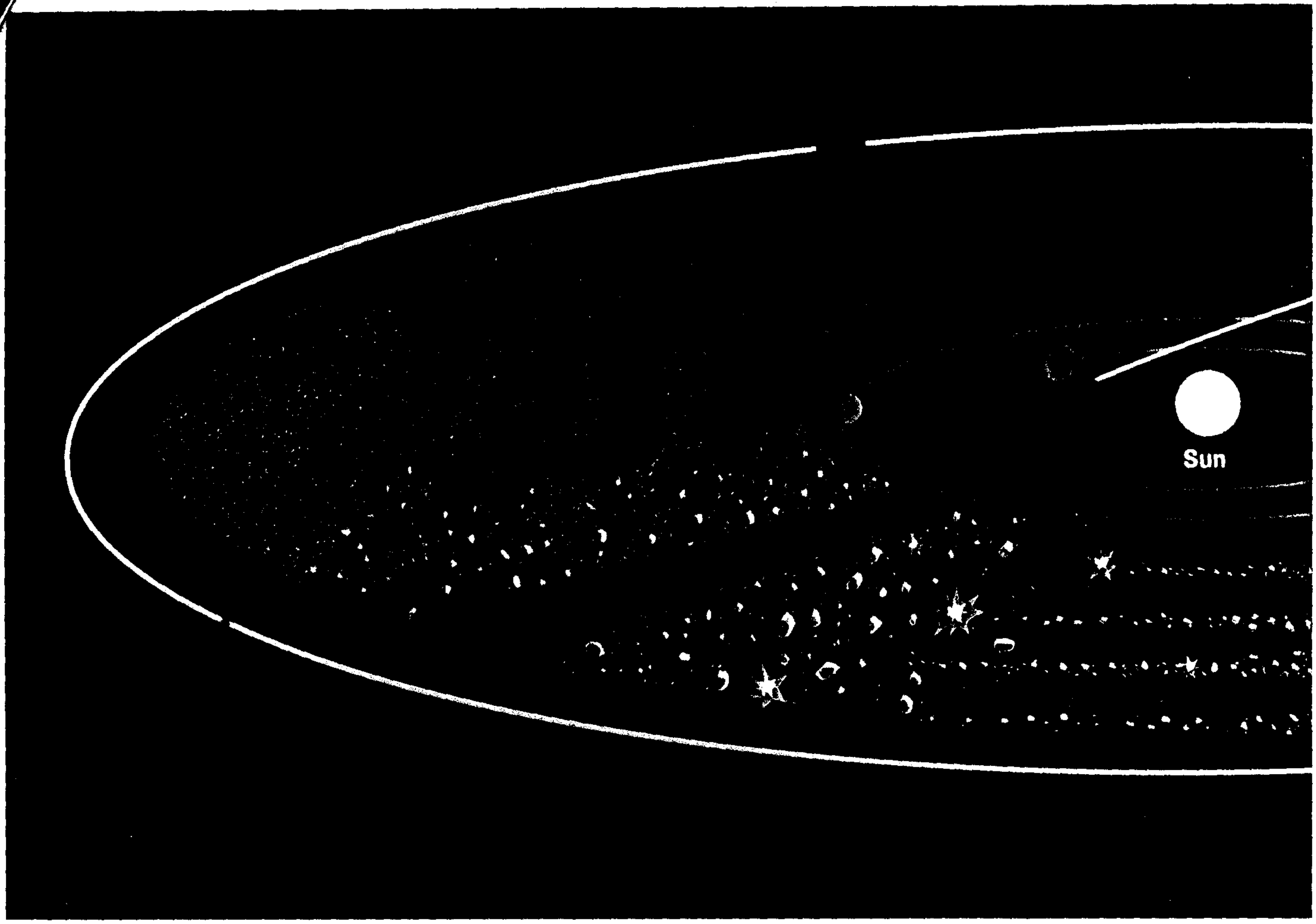
This uncompromising rejection of the presence of craters on Earth began to change with the work of Harvey Harlow Nininger. A teacher of biology and geology in Kansas in the 1920s, he was inspired by a meteor he saw in 1923 to set up a "meteor network" of newspaper editors, local officials and teachers around Kansas to report any meteoric material they found or, better yet, saw fall to the ground. While setting up this network, he found a place called the "meteorite farm" near Brenham. The owners kept plowing up bits of meteorites, which they sold to the curious and the scientific-minded. In a wheatfield on the farm, Nininger discovered a partially filled-in basin that the farmers called a "buffalo wallow" and recognized it immediately as a small crater. Subsequent excavation turned up chunks of what was undoubtedly meteoric material. Nininger had found a crater that had pieces of the meteorite that made it still inside.

Buoyed by his success, Nininger quit his teaching job and became a full-time meteorite hunter. He supported his family by selling specimens to museums and, eventually, by running a roadside meteorite museum in Flagstaff. He began his explorations of Meteor Crater by attaching a magnet to the end of a cane and walking around the crater area, picking up bits of iron from the ground. Later, he rigged a kind of magnetic rake he could tow behind his car to do the same thing. By the late 1940s he had collected enough fragments to convince scientists from the Smithsonian Astrophysical Observatory that the crater had indeed been caused by an impact explosion. They estimated that the original meteorite weighed more than 10,000 tons.

Despite this evidence, acceptance of the existence of large meteor craters on Earth was grudging. David Raup is now Sewell L. Avery Distinguished Service Professor of Geophysical Science at the University of Chicago, but he was a student in the 1950s. "We were still taught," he remembers, "that there were no meteorite craters on Earth, with one exception—the Meteor Crater in Arizona."

But sometimes you just have to believe the data. Aerial photography opened new vistas for earth scientists. Meteor Crater is less than a mile across, and it's easy for someone standing on the ground to see what it is. In a really big crater, though, one that is tens of miles across, this isn't true. You could stand in the middle of such a crater and see nothing except (perhaps) a ring of low hills—the crater's rim—in the distance. Big craters—the kind that Prinn's scenario would produce—can be seen in their entirety only from the air.

One early intimation of large craters came in 1951, when pilots taking aerial photographs of Algonquin Provincial Park in Ontario, Canada, noticed a curious feature near the town of Brent. The landforms—sides of two lakes as well as curved ridges—seemed to make up a huge ring about two miles across. Could this be



the remains of a crater three times larger than the one in Arizona?.

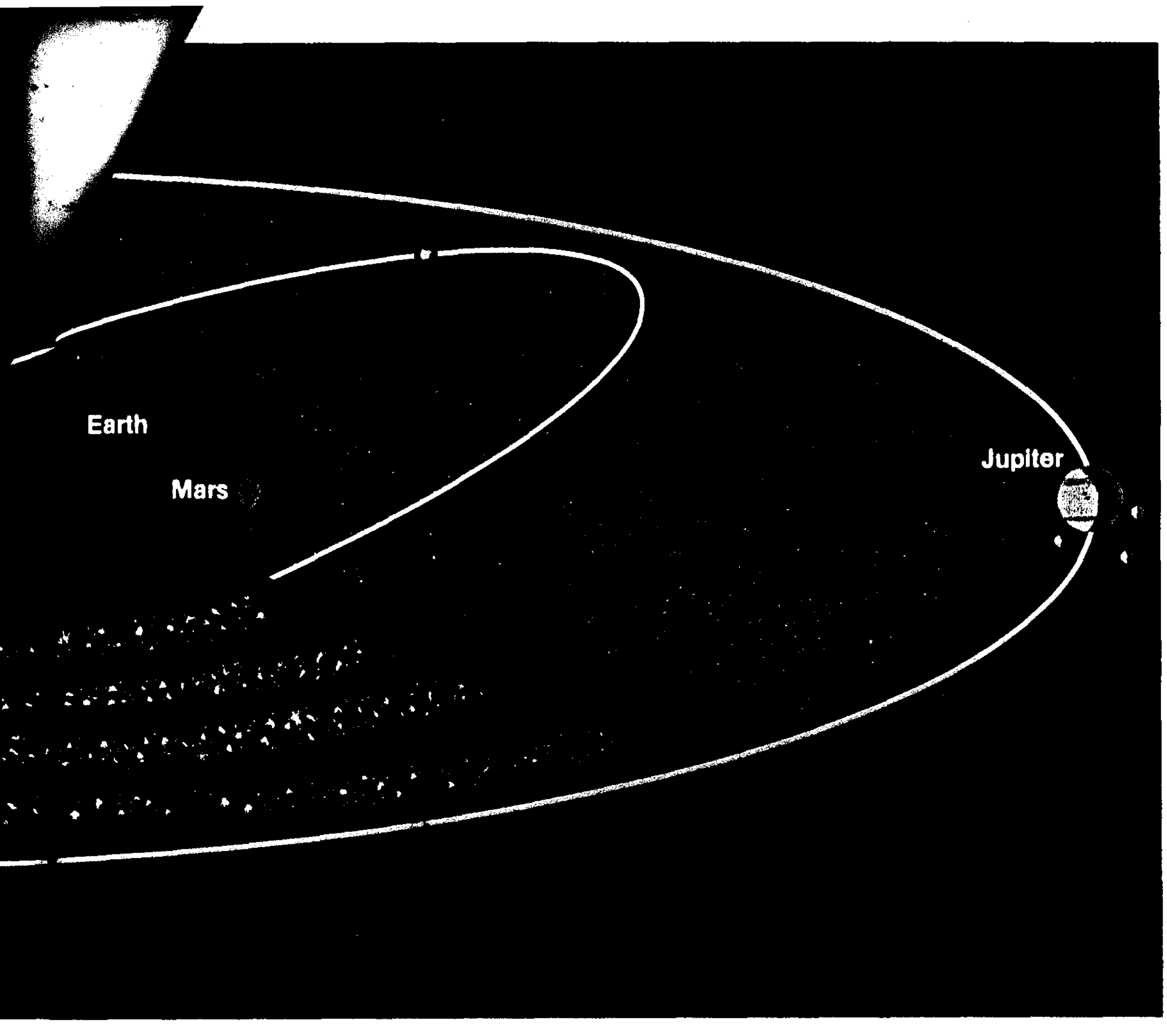
This question touches on an important aspect of craters on Earth. Unlike the Moon, where a crater will last billions of years, Earth's surface is a roiling, ever-changing environment. Over millions of years, mountain chains are raised and worn down, oceans appear and disappear. A crater created by an impact—even a crater many miles across—will be weathered down and changed over time. The challenge to geologists: recognize the remains of the crater even after eons of weathering.

To complicate matters, the existence of a circular structure in the ground isn't enough to prove that a meteorite landed. There are lots of ways to make circular structures—volcanoes, salt domes and sinkholes, to name a few. Over the years, scientists have learned to identify craters by looking at the rocks for evidence of the very high heats and pressure that have to be present when a large meteorite is stopped and explodes beneath the ground. This evidence can be in the form of minerals that can be created only at pressures much higher than those found in volcanoes, or in characteristic patterns of shattering in the rock.

There are many "craters" that have nothing to do with meteorites. Crater Lake in Oregon, for instance, is the filled-in cone of an old volcano. Another example is Hudson Bay in Canada. If you look at a map, you will see that its eastern edge is an almost perfect semicircle, a fact that led several scientists to suggest that the entire bay might be a crater. When no evidence for impact was found in the rocks, however, this notion was quietly dropped.

Once it was clear that a crater need not look like a crater, the search was on. Geologists pored over aerial and satellite photographs, searching for the telltale rings. When they appeared, an expedition to the site would be mounted and a search made for physical evidence of impact.

Gradually, the list of craters on Earth grew. Some of the entries are staggering. In northeastern Quebec, for example, is a ring of water inside a crater 60 miles across. Known as the Manicouagan Reservoir, this was the site where a meteoric object slammed into the ground more than 200 million years ago. In the intervening time, the rim of the crater has been worn away and the deep hole filled with sediments from the lake that formed in it. Today, all that's left of that cata-



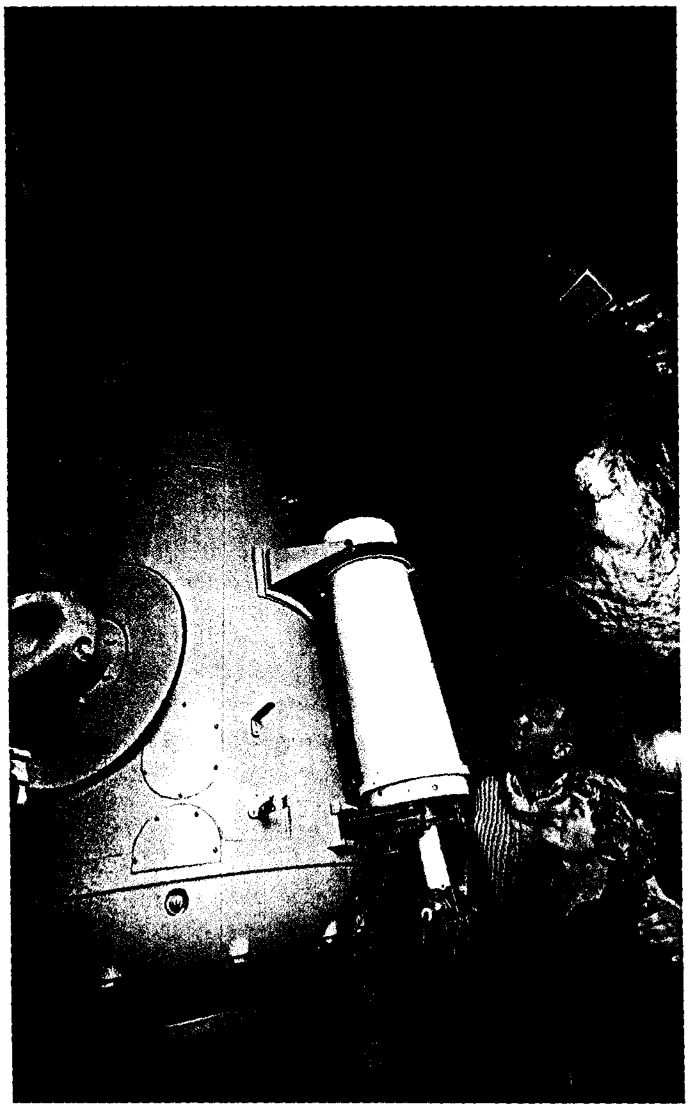
In this schematic of the life cycle of the asteroid belt between Mars and Jupiter, time starts at the rear and runs counterclockwise. Spokelike gaps mark different eras. Though a planet never formed, material did coalesce into asteroids. These collided, often ending up as fragments again (left foreground). A few were kicked out into orbits (the white trajectory) that cross that of Earth. Streams of debris gradually organized themselves into orderly lanes. As time goes by, from right to rear again, remaining fragments will grind each other down into smaller bits of planetary scrap.

Map shows impact structures known as of May 31. None has so far been found beneath the world's oceans. Density is partly a function of where scientists have done the most work; more are found every year.

strophic event is the lake ring and, of course, the evidence in the rocks.

Nor is Earth's surface the only place that craters can be found. In the normal course of geological evolution, craters can be buried deep underground. Below the flat plains of the Williston Basin in western North Dakota, oil prospectors have found the remains of a crater almost two miles underground.

The larger craters were christened "astroblemes" (star wounds) by geologist and oceanographer Robert Dietz. Today the less imaginative but probably more accurate term "impact structure" is used, and the "keeper of the keys" is Richard Grieve of Canada's Department of Energy, Mines and Resources in Ottawa. He keeps an updated list of confirmed impact structures and publishes maps showing their locations (p. 87). We know of more than 120 scattered around the world, and the list grows by five or six every year.



Eugene and Carolyn Shoemaker use 18-inch Schmidt telescope at Palomar to search for new asteroids.

The stones in our museums, visitors from distant parts of the Solar System, carry information about conditions in places no human has yet visited. Two regions are sources for objects that eventually fall into Earth's atmosphere. One is the asteroid belt, a swarm of rocks circling the Sun out between Mars and Jupiter. Asteroids are the debris left behind by a planet that never managed to assemble itself. Occasionally a collision in the belt kicks an asteroid out of orbit, sending it toward the Sun. Such asteroids take up an orbit that brings them looping in past Earth on their way to the Sun: the Apollo objects.

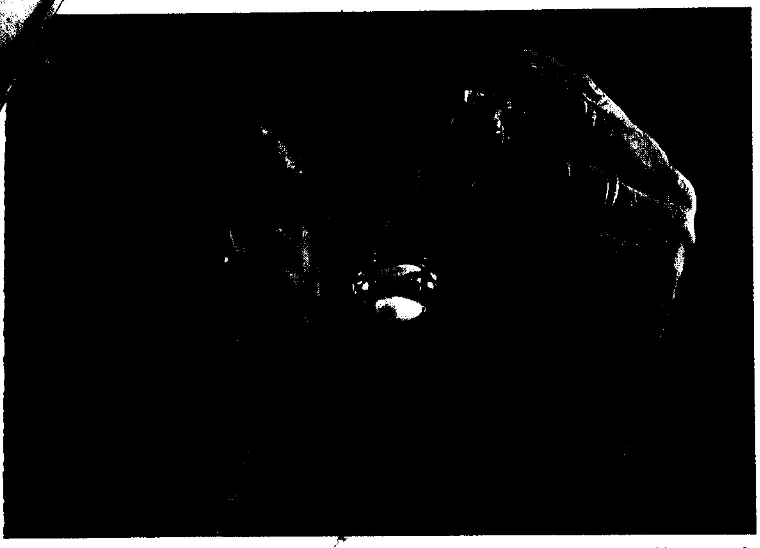
The other source is the Oort Cloud, described by the Dutch astronomer Jan Oort in the 1950s. It is a region far outside the orbit of Pluto where comets—mixtures of rock and ice—orbit the Sun. Galactic tidal forces or jostling by passing stars occasionally send these into the inner Solar System, where the heat of the Sun vaporizes some of the frozen gases and produces the tail we associate with comets. Some comets pass through the Solar System once and are gone. Others, like Halley's Comet, get drawn in by the gravitational effects of the outer planets and settle into elliptical orbits. When the gases have all blown off after too many passes near the Sun, these comets, too, become Apollo objects. Scientists estimate that only a fraction of the Apollo objects got their start as comets.

Diamonds from before the Sun was born

By studying the pieces of this scrap pile that fall to Earth, scientists can learn much about how our planet and its neighbors formed. For Edward Anders, now professor of chemistry at the University of Chicago, studying meteorites was a case of love at first sight. "When I was a graduate student at Columbia, we had a lecture on meteorites and the speaker brought samples. Just holding a piece of extraterrestrial material was tremendously exciting. As soon as I could, I started to work on them."

Capping a long and distinguished career as an "astrogeochemist," Anders recently made one of the most exciting discoveries ever made about meteorites. He has isolated what he calls "pre-solar" diamonds—grains of material made by stars before the Sun existed and that were swept up into asteroids when the Solar System formed 4.6 billion years ago. He has also found pre-solar silicon carbide (he calls it a kind of "galactic garbage"), a mixture of grains from ten or more stars.

While chemists are using the record contained in small meteorites to unravel the origin of the Solar System, other scientists are using the craters to learn



Roy Lewis holds vial containing microscopic diamonds formed before Solar System itself came into being.

about the way life has evolved on our planet. The connection between craters and evolution has been made only recently. In 1980 a group from the University of California, Berkeley, published a bold thesis: at the same time that the dinosaurs were disappearing 66 million years ago, an asteroid about five miles across hit Earth. The group was headed by a father-and-son team: the late Luis Alvarez, a Nobel Prize-winning physicist, and his son Walter, a professor of geology (below).

They had discovered that the rocks that were forming at the time of the extinction contain unusual amounts of the element iridium. This platinumlike metal is rare at the surface of the Earth, but relatively more abundant in asteroids. Their interpretation of this result: an asteroid had hit Earth, raising a worldwide cloud of dust and blotting out the sunlight for three months, causing the demise of the dinosaurs and two-thirds of Earth's plant and animal species.

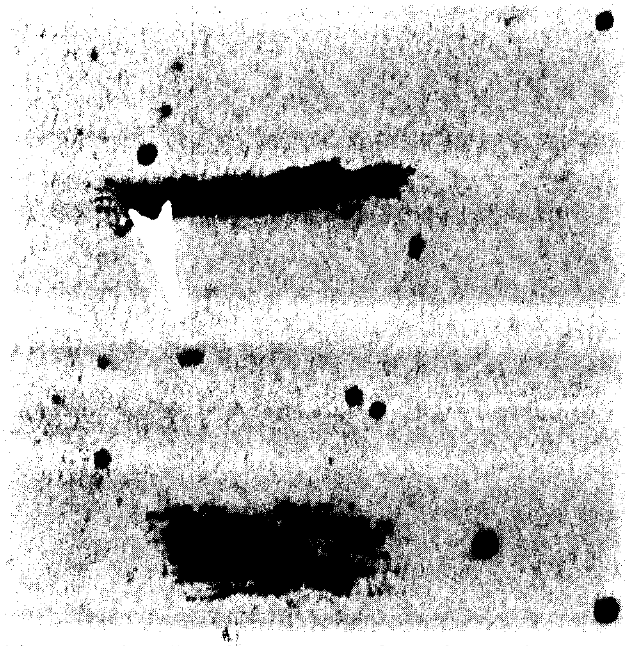
As more and more data came in, the Alvarez explanation gathered supporters. In the same places where iridium was concentrated, some investigators found shocked quartz, a mineral made only at high pressure. Others found traces of soot—evidence for worldwide forest fires caused by blazing fragments of the explosion falling back to Earth. And although scientists still heatedly debate the Alvarez hypothesis, it clearly remains one of the major contenders for the explanation of the dinosaurs' extinction.

But there is one problem with this theory: we cannot unambiguously identify the crater made by the asteroid. Some geologists have looked at the quartz that was shocked when the asteroid hit and, by plotting on a map the areas where the degree of shock is the same, have produced a series of concentric circles whose center is supposed to be the site of the crater. When this is done (and allowance made for the motion of the continents in the past 65 million years), the best candidate lies near the town of Manson, Iowa. There, buried under a few hundred feet of rubble left by the last glacier, lies a crater 25 miles across and known to us from cores brought up from boreholes. This structure may be the signature of the impact that caused the most famous of the mass extinctions.

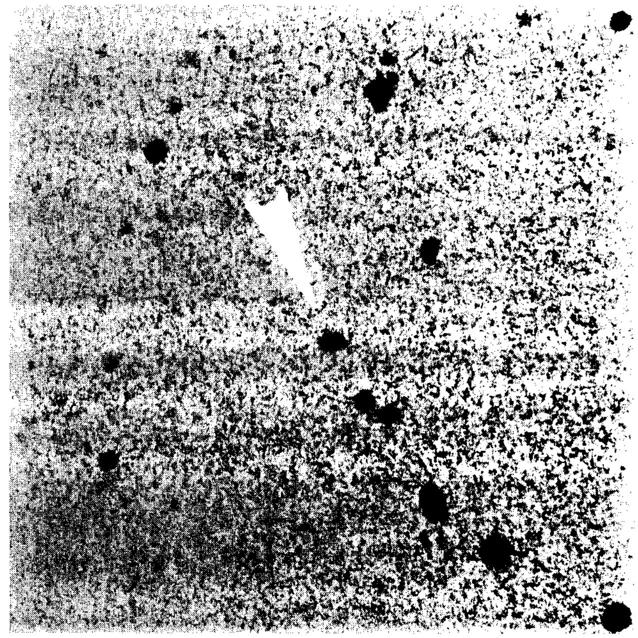
While the brouhaha over the Alvarez hypothesis escalated, NASA beefed up its investment in the ongoing search for asteroids. Scanning the skies for small, quick-moving objects, scientists are turning up several new Apollo asteroids each year.

Among the most interesting people involved in this research are Eugene and Carolyn Shoemaker. Eugene works for the U.S. Geological Survey in Flagstaff. Trained as a field geologist, back in the 1950s he was one of the pioneers in recognizing the widespread presence of meteorite craters. Over the past several years, he and Carolyn have spent months tramping around the Australian outback, adding substantially to the list of known craters. Today, they make several trips a year to Palomar Observatory where they use the 18-inch telescope to photograph the skies in their search for new asteroids. As a side effect of this search, Carolyn has become something of a celebrity among astronomers: she found no fewer than five comets during one incredible eight-month period in 1984. "Astronomers have essentially abandoned the Solar System," says Eugene, referring to the current concentration on distant galaxies and cosmology, "so the geologists came along and adopted the orphan."

The late Luis Alvarez, a physicist, and his geologist son Walter examine a clue to the dinosaurs' demise.



Pictures taken 50 minutes apart show the motion of the asteroid (arrows) that passed close last March.



Discovery came only days later. Irregular bands on left image and stray dots are from marking pens.

The mass extinction 66 million years ago could well have been caused by the impact of an Earth-crossing asteroid of the type the Shoemakers are discovering. If this were the end of the story, it would be interesting enough, but it would not change the current view of evolution. After all, there are bound to have been occasional large-scale accidents in Earth's history. What really has the community of evolutionary scientists excited is a paper published in 1983 by David Raup and Jack Sepkoski of the University of Chicago. Paleontologists have long known that there have been many mass extinctions during the past 700 million years; the disappearance of the dinosaurs is neither the largest nor the most recent. What Raup and Sepkoski discovered about the ten such events during the past few hundred million years is that they seemed to occur regularly, about every 26 million years.

This totally unexpected conclusion is still being debated, but it leads to very interesting questions. If the dinosaurs' extinction was caused by an asteroid impact, and if that extinction was just one of a regularly repeating series, could it be that every mass extinction was caused by such an impact? Could it be, in other words, that every 26 million years a mountain-size rock falls from the sky and clears the deck among Earth's life forms?

Astronomers who think about such questions have hypothesized that there are ways that such periodic bombardments could arise. The Sun, in its journey around the galaxy, for example, passes through the cluttered central plane every 26 million years. This passage could jostle the Oort cloud and send a storm of comets raging into the inner Solar System. Others have suggested that there is a hitherto undiscovered dark companion to the Sun, which was quickly nicknamed Nemesis, that comes near the Oort Cloud every 26 million years, triggering the storm.

If this conjectured cycle of destruction proves to be true, it will revolutionize the way we think about the development of life on our planet. Instead of the slow, steady replacement of one species by another, as Darwin envisioned, we would have instead a situation in which the Darwinian progression goes on for 26 million years—and then a catastrophic collision occurs, wiping out a good fraction of the species that have evolved during that time, and the whole game starts all over again.

A few scientists have even suggested that the extinction that may have been caused by the Manson asteroid (that of the dinosaurs and their cousins) cleared the way for the rise of the mammals. If it were not for asteroids bringing death and destruction to Earth, in other words, you might be reading this magazine while switching your long, green tail and admiring your bright, shiny scales.

Only about 50,000 years old, Meteor Crater in Arizona may be our planet's most familiar impact structure.