

the lower debris layer at sites in New Mexico, Colorado, and Wyoming. What's more, Shoemaker, who also studies asteroids and comets, astrophysicist Piet Hut of the Institute for Advanced Study, and their colleagues have proposed a single astronomical mechanism for multiple impacts. They envision a comet in an orbit that carries it disastrously close to the sun. The dirty snowball at the comet's heart breaks up under the stress, and the pieces slowly spread apart.

That is hardly farfetched; astronomers have watched more than 20 comets break up over the past 150 years. The additional requirement—improbable though not impossible—is that the debris field end up on Earth's orbital path. The planet's motion would then have carried it through the debris field once each year, the way Earth now passes annually through streams of comet dust that create meteor showers. That would open the way for at least two impacts, perhaps more.

As a result of these developments, more researchers are taking the possibility of a double impact seriously. But the two-impact scenario raises a host of new questions. For one, how closely spaced were the impacts? Paleobotanist Jack A. Wolfe of the USGS in Denver recently claimed an interval of less than 4 months on the basis of a site at Teapot Dome in Wyoming that he thinks preserves debris from two impacts falling into a lily pond during one growing season. That interval is a bit short even for Shoemaker's mechanism. At the other extreme, Fastovsky figures it would have taken at least 120 years for impact glass to weather into the type of clay he sees in Montana.

Another question proponents will debate: Where are the craters from two separate impacts? Izett and Shoemaker suggest that

meeting, he described work with Douglas Martinson of Lamont-Doherty Geological Observatory of Columbia University in which the researchers compared the behavior of the field recorded during a reversal 1.1 million years ago in North Atlantic and equatorial Pacific sediments and in lava flows at one site in the South Pacific. This diversity of records should eliminate any distortions present in a single region or recording medium, says Clement. The result: consistent indications that "at least in this one reversal there is strong evidence for a dipolar field" during a flip-flop.

Soon it will be the theorists' turn to make sense of the reversing field, says Clement. "If we can give them some constraints as to what is happening during a reversal, they can get more constraints on their models" of the field.

■ RICHARD A. KERR

the 180-kilometer Chicxulub structure in the Yucatan is responsible for the lower layer. Circumstantial evidence is mounting that it was linked to the mass extinction (*Science*, 15 November 1991, p. 943), and as the largest known impact, it would have had the power to blow enough debris into central North America to form the thicker lower layer. For the upper layer, the 32-kilometer Manson crater in Iowa seems right, Izett and Shoemaker say. On its own,

Manson had seemed a poor candidate for being the killer crater because of its small size—it released one two-hundredth as much energy as the Chicxulub impact.

The giant Chicxulub impact probably would still have been the primary driver of the mass extinction, says Shoemaker, but it could have had a little help from its Iowa companion—and perhaps from other impacts as well. The search for killer craters may not be over soon.

■ RICHARD A. KERR

Extinction With a Whimper

Few researchers now doubt that a comet or asteroid—or several in quick succession (see story on page 160)—struck Earth at the time of the mass extinction 65 million years ago. It might seem reasonable to assume that all the species that vanished in the mass extinction were victims of the impact. But there is growing evidence that some species were in trouble before the impact, probably because of gradual environmental change.

One of the strongest indications yet of a gradual component to the mass extinction comes from an early application of a new dating technique to paleontology. Stratigrapher Nicola Swinburne of the University of California, Berkeley, has reaffirmed that rudists, bizarrely shaped bivalves that lived much as corals do, disappeared gradually before the impact.

Swinburne's study, reported last month at the American Geophysical Union meeting in San Francisco, is only the latest to find that the rudists declined gradually, but it sports an important distinction. Like other researchers, Swinburne combined fossil finds reported from around southern and central Europe, North Africa, and Arabia, carefully weeding out inconsistencies in classification. But in establishing a chronology of the species' disappearances, she abandoned the usual strategy of relying on marker fossils of an assigned age as benchmarks—a technique she says can distort the rudist record. Instead, she took advantage of the steady change in the ratio of two strontium isotopes in seawater during the 12 million years before the impact to date the rudist shells themselves, based on their isotopic composition.

Swinburne's isotopically dated compilation paints a clear picture of gradual extinction. From a peak in the number of extant species and genera about 75 million years ago, rudist diversity went into a sharp decline about 70 million years ago. Some researchers have seen a sequence of abrupt drops and intervening plateaus in the decline of rudists around this

time, which they have interpreted as evidence of a drawn-out shower of killer comets. But the decline Swinburne traced was steady. Such "stepwise" extinctions only appear when the database is poor, she says.

Rather than some extraterrestrial influence, the steady decline in rudist diversity points to an environmental cause, says Swinburne. The diversity decrease paralleled a decrease in the area of shallow marine waters, the rudists'

habitat, as the seas retreated from the continents. Swinburne concludes, as others have, that the retreat drove most of the rudists' decline. And the resulting extinction, which traditionally had been lumped into the mass extinction of 65 million years ago, seems to have come before the impact; the youngest rudists in Swinburne's compilation fall more than a million years short of it.

"After years of anecdotal evidence," says paleontologist David Jablonski of the University of Chicago, "it would appear that hard data are beginning to emerge suggesting" that environmental changes during the few million years before any impact were already gradually taking their toll. With Swinburne's study, that notion would seem to be established firmly for the rudists. Moreover, another major fossil group—the bivalve inoceramids—also shows signs of a gradual disappearance, shortly before the impact.

On the other hand, the dinosaurs, the spiral-shelled marine ammonites, freshwater clams in Montana, and plants in North Dakota seem to have been getting along just fine until they disappeared from the geologic record right where the impact left its mark (*Science*, 11 January 1991, p. 160). But there's no reason why the mass extinction need be explained exclusively by a single mechanism, notes Jablonski. Maybe the worst mass extinction of the past 200 million years was the result of a catastrophe that happened to strike just when things were already going downhill.

■ RICHARD A. KERR



Lingering death.
A rudist.