Target Earth

Geologists link a chain of craters

By RICHARD MONASTERSKY

In one of the most awesome sights of prehistory, the earliest dinosaurs may have looked up from their evening meals to witness a mountain hurtling through the sky. Blazing white-hot and moving at 61,000 kilometers per hour, the giant comet or asteroid screamed through Earth's atmosphere—possibly close enough to snap the tops off any high peaks in its path. Then the object disappeared back into space, missing the planet by the thinnest of margins.

These late Triassic reptiles could not have guessed that the sky streaker would return shortly—this time, in force. The extraterrestrial menace split into a series of large chunks that slammed sequentially into Earth, like bullets from a machine gun.

Although this scenario sounds like a product of the impact-obsessed movie industry, it is actually emerging from scientific studies of five ancient craters in North America and Europe. A team of geologists proposes that all five formed within a few hours of each other 214 million years ago, with possibly planet-wrenching consequences.

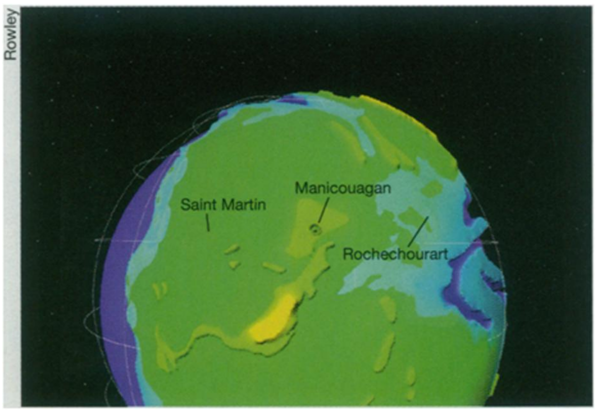
"I can't imagine that this event would not have had a catastrophic effect on Earth," says John G. Spray, whose work with two colleagues has connected the separate events. "When you add up the three biggest craters, the energy released [in these impacts] would have been comparable to, if not more than, that of the Chicxulub impact, which wiped out the dinosaurs 65 million years ago," says Spray, an impact geologist at the University of New Brunswick in Fredericton.

Spray's road to discovery started in France in 1994, when he visited a cryptic scar in Earth's crust. Called the Rochechouart impact structure, the feature measures about 25 kilometers in diameter and is so worn by erosion that it no longer looks like a crater.

While at Rochechouart, Spray collected samples of rock that had been melted by the impact and sent them to Simon P. Kelley of the Open University in Milton Keynes, England. Using a technique that relies on the slow radioactive decay of potassium to argon, Kelley determined that the rock had melted between 222 million and 206 million years ago, most likely at 214 million years ago.

"That age struck me straight away because it's the same age as the Manicouagan impact structure here in Canada," says Spray. "So then we got to thinking that if those two have very similar ages, let's look at the list of 150 or so impact structures that are documented and see if any of those have similar ages. And we found three others, making five altogether."

From the vantage of space, the Manicouagan feature is easily visible, thanks to the Quebec authorities, who flooded sections of the crater to make a reservoir. An almost perfectly circular ring of water now surrounds the raised center of the crater, creating a lake that looks like an eyeball on satellite images and even appears on ordinary maps.



Blasts from the past: In the late Triassic period, the continents formed a giant landmass called Pangaea, shown in green. The Saint Martin and Rochechouart impacts punched out craters equidistant from the central Manicouagan crater and lined up parallel to the equator.

The complete Manicouagan structure is 100 km in diameter, placing it within the top six largest craters known on Earth. Geologists had previously dated it as 215 million to 213 million years old.

In Spray and Kelley's search for craters of a similar age, they found a third large example called the Saint Martin impact structure, located northwest of Winnipeg, Manitoba. Mostly hidden beneath younger rocks, the crater measures about 40 km across. Researchers have dated it to 219 million years ago, with a large uncertainty of 32 million years on either side.

Their analysis also picked up a 15-km-wide crater in Ukraine and a 9-km-wide one in North Dakota, both of which have loosely determined ages that could overlap with the other three impacts.

Armed with these five roughly coeval craters, Spray sought to plot the impacts on a map of Earth. "But the problem, of course, is that the present-day orientation of the [continents] was not how they were 214 million years ago," he says.

Earth's outer shell is broken up into a dozen large plates that continuously migrate around its surface. To determine the craters' ancient locations, Spray worked with David B. Rowley of the University of Chicago. When Rowley located the craters on a map of the world 214 million years ago, Manicouagan, Rochechouart, and Saint Martin fell almost perfectly in line.

Even more surprising, says Spray, all three had the same paleolatitude of 22.8°N, meaning that the line through them parallels Earth's equator. Moreover, Saint Martin and Rochechouart lay almost equidistant on either side of Manicouagan, forming a remarkably regular string 4,462 km long.

The two remaining craters do not lie on this paleolatitude, but their positions are also noteworthy. When the researchers drew lines connecting each small crater with the larger one nearest it, the lines were parallel, running northeast to southwest, report Spray, Kelley, and Rowley in the March 12 NATURE.

The new study has had far more impact than previous claims regarding crater chains on Earth. In the past, most researchers have discounted reports of craters that line up (see sidebar). Spray is now trying to tighten his case by precisely dating the Saint Martin structure to see if it formed at the same time as Manicouagan and Rochechouart. "It's not absolutely proven that ours is a chain. If Saint Martin comes out within the error of the other two, I'll be satisfied."

Even that evidence might not convince skeptics, who think the alignment of craters may be coincidental. "They sort of have the same age, and they sort of line up," says Richard Grieve of the

Geological Survey of Canada in Ottawa. Although more dating work can refine the ages of these features, he says, "I don't think we're ever going to be able to say for sure based on isotopic ages, because they can't get these down to a day or a week." At best, radiometric techniques can indicate whether these impacts took place within a million years of each other.

Dennis V. Kent of Columbia University's Lamont-Doherty Earth Observatory in Palisades, N.Y., has tried to check the hypothesis by looking at magnetic studies of rocks from Manicouagan and Rochechouart conducted in the 1960s and early 1970s. As rocks cool from a molten state, they record a snapshot of Earth's magnetic field, which occasionally turns over, switching north and south magnetic poles. If the craters had the exact same age, reasoned Kent, magnetic particles in their rocks should have the same orientation.

According to the available evidence, however, rocks from the two sites have opposite orientations, indicating that the direction of Earth's magnetic field reversed in the interval between impacts. Geomagnetic researchers think that it takes thousands of years to reverse the field.

Kent says his simple test argues against the likelihood that these two craters formed hours apart, leaving unexplained the straight line with the Saint Martin crater. "That alignment is interesting, I confess," he says.

Spray contends that the magnetic test results may not be as clear-cut as they initially seem. Because the Manicouagan crater is so much larger than Rochechouart, the molten rocks would have cooled much more slowly at the Canadian site, taking thousands or hundreds of thousands of years longer to lock in a record of Earth's magnetic field. "There are a number of reasons why the differences in polarity of the two [craters] can be explained. I don't think it necessarily means that they did not in fact form at the same time," he says.

If Spray and others can strengthen their claim of an impact chain, it would raise some problems. Standard theories say there is almost no chance of finding such a string of craters on Earth.

"It's intriguing, and if it's true, it causes great headaches for us theoreticians," comments H. Jay Melosh of the University of Arizona in Tucson. Earth's gravity is not considered strong enough to capture a comet except in very unlikely situations.

In 1994, planetary scientists received a vivid lesson on how crater chains can form on a larger planet. That July, comet Shoemaker-Levy 9 plowed into Jupiter, raising a line of dark welts (SN: 12/17/94, p. 412).

The comet had started out as a single body that strayed too close to Jupiter sometime this century and was trapped in an orbit around the planet. On a close pass by Jupiter in 1992, the planet's gravity tugged the weakly constructed comet apart, severing it into at least 20 large pieces aligned like a string of pearls.

On the comet's next pass, in 1994, the fragments plunged into the atmosphere one by one over a period of 6 days. Because Jupiter rotated several times during this span, the identically aimed fragments struck different points, all falling on the same line of latitude.

These observations originally led Spray to suppose that a similar process might explain the string of late Triassic craters on Earth. Planetary scientists, however, regard this scenario as highly unlikely because Earth's gravity is so much weaker than Jupiter's. "The probability for this type of capture is 100,000 times less for Earth than it is for Jupiter," says Melosh.

A potential solution comes from William F. Bottke of Cornell University. Last year, Bottke and his colleagues proposed that a crater chain might develop when an object passes so close to Earth it almost scrapes the surface. At that intimate distance, it would pass through the atmosphere and fall prey to an array of destructive influences, such as intense air friction, that could combine to shatter the object.

Flying through the atmosphere, the asteroid or comet would lose enough energy to enter an elongated orbit around the planet. On the next pass, these now well-separated fragments would sequentially strike Earth. The return could take several days or months, says Bottke.

Melosh notes that this model has merit, but he is unconvinced that it would actually work.

Bottke admits his model cannot explain every aspect of Spray's discovery—for instance, why the two smaller craters lie off the main line of the other three—but says it requires more study. When he first came up with the idea, there was no solid evidence that this type of event had actually happened on Earth. "It seemed like a neat scenario, but until we found an [example], it was kind of hard to get excited about it. Now, we get to do all the fun stuff and rework it."

At first glance, the multiple impact scenario ends in true Hollywood fashion: with death on an epic scale and the survival of a

The crater chain that wasn't

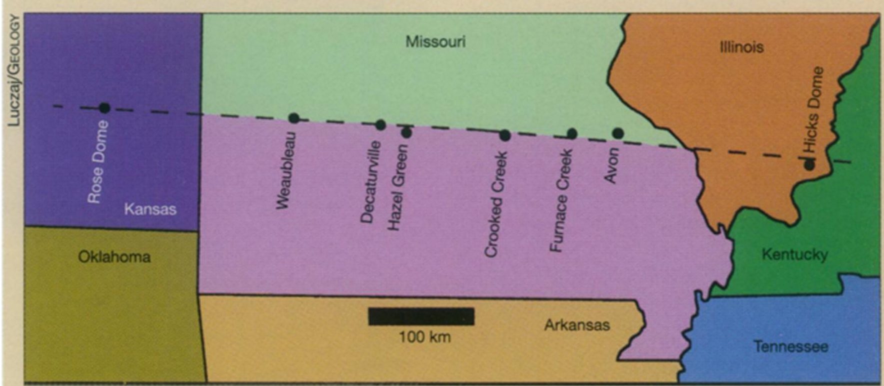
A series of eight craterlike formations runs through the U.S. heartland, forming a remarkably straight line that passes from Kansas through Missouri into Illinois. Two years ago, geologists Michael R. Rampino and Tyler Volk of New York University argued that the structures were all impact craters created at the same time by a string of comets or asteroids.

The midcontinent features would have constituted the first known crater chain on Earth, but many geologists dismissed the claim. In the April GEOLOGY, John Luczaj of Johns Hopkins University in Baltimore presents what may be a death blow to the idea. If multiple impacts formed the line, then they must have identical geologic ages, he argues. The evidence, however, points to ages ranging from 500 million to 100 million years.

"Clearly they are not the same age, and since that is the fundamental test for an impact string, you can rule out that hypothesis," says Luczaj.

Although many geologists agree, Rampino and Volk respond that the dates of the craters need to be better established.

Crater specialists add that only two of the structures in Missouri show convincing evidence of having formed during impacts. The other examples don't have any obvious impact evidence and may have a volcanic origin, says H. Jay Melosh of the University of Arizona in Tucson. —*R. Monastersky*



Line of fire: The eight circular geologic structures on this map have aroused debate for decades. Geologists have found evidence of impacts only at Decaturville and Crooked Creek.

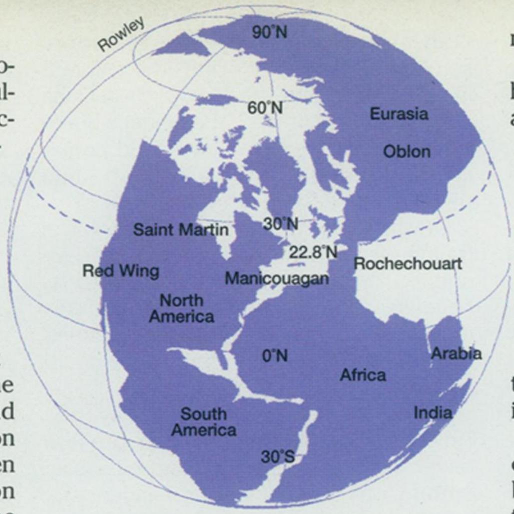
charismatic character.

The close of the Triassic period is notorious among paleontologists as a tumultuous time. One of the five biggest extinction events in the fossil record, the late-Triassic crisis wiped out the dominant reptiles of the time and helped spur the rise of a hitherto minor group called the dinosaurs, which went on to dominate Earth for 150 million years.

On closer inspection, however, the neat story line dissolves. The biggest burst of extinctions took place at the boundary between the Triassic and Jurassic periods, just about 202 million years ago, says paleontologist Paul Olsen of Lamont-Doherty. Some 12 million years separate the impacts from the most prominent Triassic die-offs.

Spray and his colleagues suggest a tentative link between the impacts and an earlier wave of extinctions, which occurred at the boundary between the Carnian and Norian stages of the Triassic. Geologists have not dated this time precisely, he says. "Although it is generally held to be 220 million years ago, it could easily be close to 214 million," contends Spray.

Paleontologist Michael J. Benton of the University of Bristol in England disputes that point. "Nobody has suggested [the Carnian stage] goes to 214. There is no secondary evidence that impacts had anything to do with the Carnian-Norian extinctions."



A map of the late Triassic period shows outlines of the modern continents and five approximately contemporary craters (circles). An arc through the Rochechouart and Obolon craters runs roughly parallel to an arc passing through the Saint Martin and Red Wing craters.

Olsen echoes the skepticism. The age of the Manicouagan crater, he says, "falls in the middle of the Norian, but there is no evidence of anything going on in the middle Norian. There are no extinctions."

Geologists might find the lack of association even more interesting than a link between the impacts and extinctions. A string of five large body blows to Earth may not be enough to knock life for a loop.

The Manicouagan crater is a little over half the size of the Chicxulub crater, but according to impact theories, it is large enough to cause many of the same effects. With Manicouagan and the other four craters, says Spray, the energy released in that series of strikes should compare with the large Cretaceous collision.

Many researchers, however, are starting to think that size does not matter—above a certain point. Location may be the more important factor in determining the killing potential of a large impact.

By this rationale, the Cretaceous crash claimed so many species because the body slammed into a relatively rare rock type, a thick carbonate platform loaded with sulfur-rich rock. The crash filled the atmosphere with tiny, light-blocking sulfuric acid droplets, which eventually dropped into the oceans and turned the surface waters toxic. Carbon liberated during the crash enhanced Earth's greenhouse effect and warmed the planet.

"I'm beginning to think that Chicxulub might be unique because of the target rocks and all the sulfur that went into the atmosphere," says Grieve.

If Earth suffered several simultaneous hits 214 million years ago with few lasting biological effects, then scientists may have overdramatized the threats of life-ending strikes from space. That lesson, however, will not make a splash in Hollywood. □

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female who is synchronized with her competitors can be reasonably assured that the alpha male will not impregnate them.

Eric Carlisle
Dallas, Texas

Local feedback on LTER

"Ecologists Go to Town" (SN: 4/4/98, p. 219) missed a critical component of the Baltimore Urban LTER's success.

The Baltimore LTER is made up primarily of local co-principal investigators and their staffs at Johns Hopkins University, the University of Maryland at College Park, and the University of Maryland, Baltimore County, where the LTER research office, site manager, and staff are located. In addition, significant staff and resources are being provided by the local offices of the U.S. Geological Survey, the Bureau of the Census, the Environmental Protection Agency, and NASA's Office of Earth Science. Participation by state, county, and city agencies, as well as others has also been a major help in data acquisition and logistics.

These local institutions and researchers and their spirit of cooperation are what make the Baltimore LTER a candidate for long-term success in integrating the social, ecological, and physical disciplines for understanding urbanized areas as ecosystems.

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