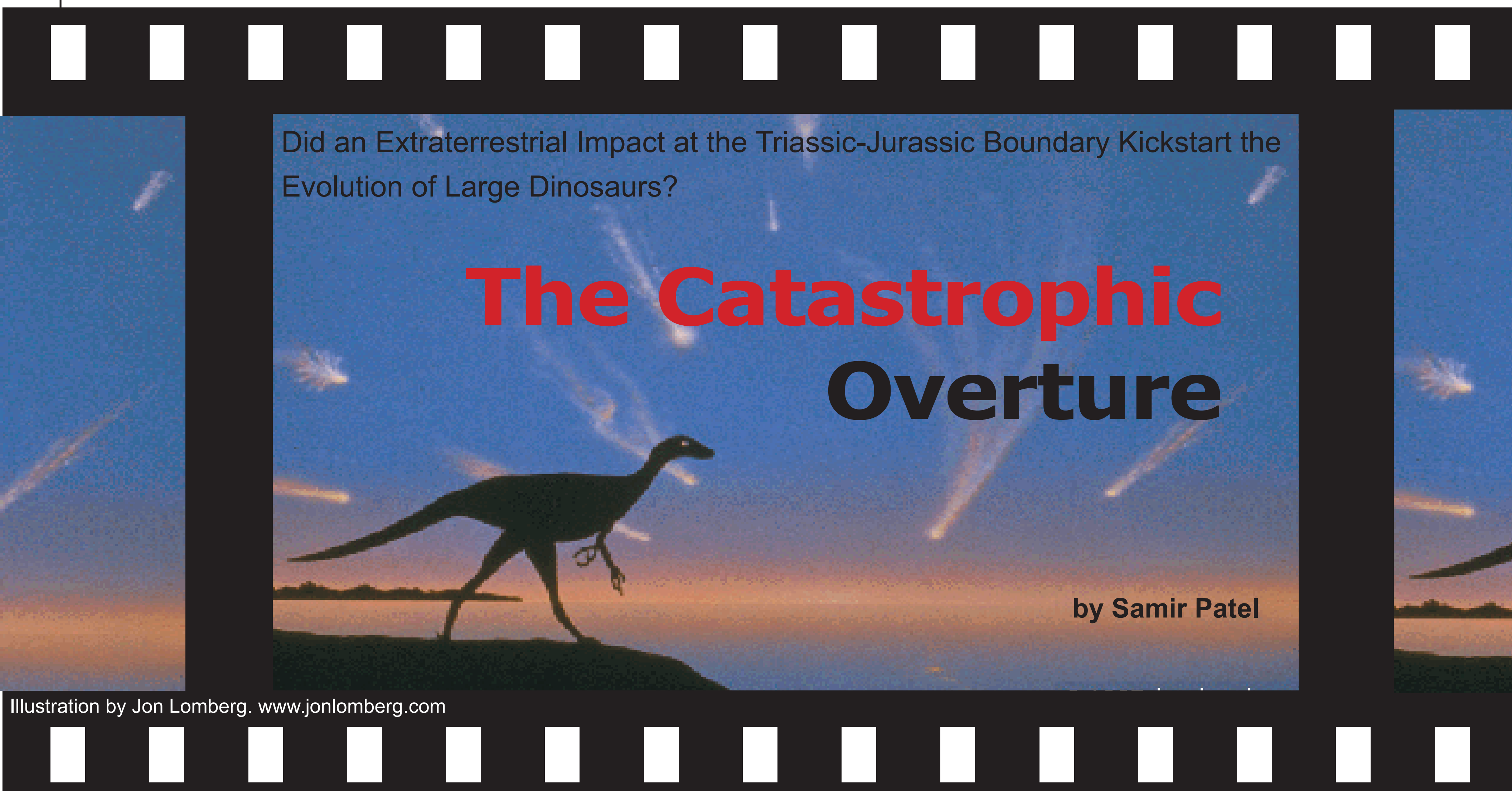

Did an Extraterrestrial Impact at the Triassic-Jurassic Boundary Kickstart the Evolution of Large Dinosaurs?

The Catastrophic Overture

by Samir Patel

Illustration by Jon Lomberg. www.jonlomberg.com

Sixty-five million years ago we were freed by a rock from space. That is to say, the common ancestor that we share with all mammals was freed from the 135-million-year reign of dinosaurs by the impact of an asteroid 10 km across traveling 30 km/s. The celebrated cataclysm between the Cretaceous and Tertiary Periods—known in the rock record as the K/T boundary—was the end of one regime and the beginning of another. The survivors of the mass extinction, including small mammals scurrying through the underbrush, experienced "ecological release," an opening of niche space that probably allowed the evolution of the tremendous diversity of mammalian forms that inhabit the world today. Now there is evidence that the dinosaurs may actually have been victims of a karmic boomerang—they may have been liberated in a similar way 135 million years prior.

Paul Olsen of Columbia's Lamont Doherty Earth Observatory theorizes that an extraterrestrial impact occurred 202 million years ago between the Triassic and Jurassic Periods (the Tr/J boundary), freeing small carnivorous dinosaurs from large reptilian competitors and allowing them to evolve the massive size that has inspired Hollywood special effects technicians for decades. It makes for a grand tale, the rise and fall of a dynasty. The theory could give structure, a narrative arc, to one chapter in the long and complicated story of evolution. This framing device certainly is tantalizing, but for now it resides in the realm of theory. The patterns are there, but many more data will be needed before the theory can reach the level of acceptance enjoyed by its K/T cousin.

"When you look at specific sections at the Triassic-Jurassic boundary," Olsen says, "where the fossil record is good, [it] shows for the fossils that are present an abrupt transition." But even that seemingly simple statement, like almost every other part of Olsen's theory, has its critics. "Two hundred years of fossil collecting across the Tr/J boundary do not document a mass extinction. That's all there is to it," says Spencer Lucas of the New Mexico Museum of Natural History & Science. Olsen, whose easygoing enthusiasm sometimes betrays frustration with such criticism, bases his impact theory on a suite of observations that echo the K/T boundary. The evidence is compelling, but piecing together events—even global catastrophes—that took place 200 million years ago is tricky business.

Olsen does much of his work on the boundary in the Newark Supergroup, thick successions of sedimentary rock in Eastern North America that were once rift lakes much like those in East Africa today. These rock sections record changes in global climate, contain ancient mudflats that preserved the footprints of the locals and provide several intriguing pieces of evidence for an impact at the Tr/J boundary. Most significantly, Olsen recently reported in *Science* a hint of the characteristic signature left by the K/T impactor—an iridium anomaly. The metal iridium is rare on the surface of the earth but exists in higher concentrations in the earth's interior and in extraterrestrial objects. At the K/T boundary there is a narrow, almost global layer of clay with a concentration of iridium much higher than normal—one of the strongest pieces of evidence for a disaster from the sky. Olsen's anomaly is far smaller than the one at the K/T, leading some to theorize it might actually be volcanic in origin.

The rocks also record a change in fossilized pollen. It is known that fossils of all kinds change across the geologic boundary—in fact that is how such boundaries are defined—but right at the boundary Olsen and his colleagues found a sudden jump in the presence of fern pollen. This so-called fern spike, which also is observed at the K/T boundary, is associated with the initial recovery from an ecological disaster. Even today opportunistic ferns often are the first to move in after a disturbance. There also are carbon isotope changes associated with the boundary, which indicate some kind of global change in how carbon cycles through the atmosphere, ocean and organisms. An impact that killed off the tiny but influential aquatic organisms that form the basis of marine food chains could cause this, and the same pattern of isotope changes are observed at the K/T boundary. But there are other potential explanations, including some—again—tied to volcanism.

All these observations coincide with a change in fossilized footprints, which tell an interesting story. They appear to track a sudden large extinction followed by an evolutionary lurch in which carnivorous dinosaurs quickly grew in size. Prior to the boundary there was a diverse assemblage of terrestrial species. The large carnivores at this time were reptiles—squat and sometimes sail-backed rauisuchians and crocodile-like phytosaurs—and the largest dinosaurs were modest-sized herbivores called prosauropods. There was global diversity as well; fossil beds in other parts of the world contain different groups of species.

After the boundary, however, diversity appears to plummet. Terrestrial communities are dominated by a much smaller group of lizards, crocodilians and carnivorous dinosaurs called theropods. Interestingly, Olsen says this phenomenon is global—all over the world the very Early Jurassic is dominated by similar species-poor communities. Notable in this section is

Larger theropod footprints began to appear in the Jurassic period, supporting Olsen's impact theory. The image on the left is the largest Late Triassic theropod track, while the image on the right is an example of the earliest Jurassic theropod track *Eubrontes giganteus*. The increase in track size of twenty percent indicates a doubling of body mass.

Courtesy of Paul Olsen

the first appearance of *Eubrontes giganteus*, a carnivorous dinosaur whose tracks are 20 percent larger, which correlates with a doubling of body mass, than any theropod track before the boundary. This observation is consistent with ecological release; the large reptilian predators were swept off the earth and large dinosaurs rose up in their place. Of this Olsen is confident, but doubts about his evidence are common. For example, some claim that large carnivorous dinosaurs could have existed before the boundary. "What [the critics] have to do if they disagree with the observations around the Triassic-Jurassic boundary of eastern America, they have to come up with some observations that show that's incorrect," says Olsen. There is one problem: such evidence may exist. A footprint found in Australia in the 1960s is larger than *Eubrontes* and was dated to 20 million years before the boundary. According to Lucas, the Australian footprint was a glaring oversight on Olsen's part and falsifies his ecological release theory. "It was an embarrassingly bad mistake," he says. Olsen counters that the cast of the footprint is incomplete and may not be from a dinosaur at all. But it is not out of the realm of possibility, he concedes, that an impact could have cleared the way for a large species, a superpredator, from another part of the world to migrate into the Newark Basin.

Olsen admits that the evidence for an impact is "still rather paltry," but most of his observations are constrained within 50,000 years of sediments around the boundary—a blink of the eye in geologic time. More evidence needs to be found, particularly in other locations, to establish the global scale of the event. "I would argue that the iridium anomaly that I describe has to be shown to be present in other sections, and that's just an incredibly labor-intensive operation," admits Olsen. "Work on that is underway, but it's going to take a long time."

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"It is viable," says Lawrence Tanner of Bloomsburg University in Pennsylvania of Olsen's impact theory, "but it still falls far short of the evidence we have of an impact at the Cretaceous-Tertiary boundary."

In fact, many more data will be necessary to convince some. "[Olsen]'s made a monumental contribution and he'll continue to. That doesn't mean he's always going to be right. And I'm more than happy to point out where I think he's wrong," says Lucas. Lucas and others, including Tanner and Peter Ward of the University of Washington, argue that the Tr/J extinction was a puny afterthought to a series of two to four earlier step-wise extinctions. This alternative theory paints the world of the Late Triassic as a very unpleasant place, a seething greenhouse wracked by repeated paroxysms of extinction. Proponents of this theory argue that the belief in a mass extinction is the result of using poor temporal resolution, which leads to the artificial lumping of separate events. Olsen disagrees. "It's legalese. It's arguing science like a lawyer," he says, positing that because fossils are discrete data points, looking at small portion of the rock record will always give the illusion of a step-wise pattern due to a sampling artifact called the Signor-Lipps effect. "In reality, it's extremely difficult to demonstrate a step-wise extinction because all extinctions will look step-wise in the fossil record at some level of sampling around a boundary that was catastrophic," he adds.

Poor resolution is a real problem in the rock record. It can be difficult to determine when a species went extinct or the rate at which a mass extinction occurred. Some groups of marine fossils, for example, which are used to define geologic boundaries because of their relative abundance, appear to wink out before the boundary, but others go out with a bang right at it. Another problem lies in correlating terrestrial and marine sections. The fossil record is capricious in this way, so it can be hard to come down in favor of one theory or the other. "Did this event cause the instantaneous extinction of all these creatures or is it just simply correlated with the extinction of all these creatures or is the record so crappy worldwide that we can't even really tell that these things all went extinct all at the same time anyway?" asks Mark Norrell of the American Museum of Natural History. "I'm sort of thinking of the latter."

Whether the extinction occurred all at once or in a series of steps may have an effect on theories about its cause. A sudden mass extinction may be better explained by an impact, a sudden global event, Photo by NASA

MANICOUAGAN PENNINSULA, Quebec, a candidate crater site for Olsen's proposed Triassic-Jurassic boundary.

earth belches its way through a series of environmental changes. However, Olsen is quick to point out that if volcanic activity was the cause of the observations, it would be the first of its kind; there is no precedent for an iridium anomaly caused by volcanism. Two of the proposed mechanisms—impact and volcanism with methane release—are not necessarily mutually exclusive. An impact could have been the coup de grace that polished off taxa that had staggered through the first few extinctions. "This issue really comes down to what percentage of the extinction event does that impact explain," says Neil Shubin of the University of Chicago.

One discovery that would strengthen Olsen's position would be while a series of extinctions might be more likely to be caused by an ongoing earth-based process. It may come down to a question of parsimony—which mechanism provides the simplest explanation for the observations?

Olsen argues that the impact makes the most sense because the observations match a well understood pattern—that observed at the K/T boundary. "I prefer the parsimonious explanation, that both events were due to the came causes," he says via e-mail. In fact, he places the burden of proof on those who believe the extinction was step-wise because they will need many more data to make their case. The other side of this argument asserts that it makes more sense to look for a known earth-based mechanism that can explain all of the observations, rather than to rely on the *deus ex machina* of an extraterrestrial visitor. A few potential culprits for this mechanism have been proposed. It is known that around the Late Triassic and Early Jurassic the Central Atlantic Magmatic Province (CAMP), one of the largest volcanic releases ever, was active. While most of this volcanic activity, which covered 10 million of km^2 with basalt over the course of 1 to 2 million years, is believed to have taken place after the Tr/J boundary, related activity might be able to explain the iridium anomaly. Also, outgassing associated with the volcanism and the release of methane from ocean floor sediments could begin to explain the carbon isotope changes. Step-wise extinctions and a fern spike might result and the

a big hole in the ground. The K/T crater was found on the coast of Mexico, but if a Tr/J impactor hit the ocean, its crater almost surely would have been subducted below another crustal plate by now. But if it landed on a continent there would be a scar, and there is a potential candidate—the Manicouagan Crater in northern Quebec. The current date of the Manicouagan places it several million years before the boundary, but "there's reason to believe that the age that's commonly reported and accepted in the literature might be a little too old," according to Andy Winslow, a graduate student at SUNY Stony Brook who is redating the crater. Older grains taken as part of samples may have skewed the dating, making the crater appear older than it is.

Even if the Manicouagan redating comes back right at the Tr/J boundary, the issue still may not be settled because of lingering questions about the nature of the extinctions. And if the crater does not correlate with the boundary, scientists will be left to determine what, if any, effect that impact actually had. Theoretical capacity is up to the task, but the data are lacking, so scientific consensus on the Tr/J boundary will remain elusive.

"This one ain't over," says Lucas. "The fat lady isn't going to sing on this one for a long time."

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