The Greatest Extinction Gets Greater

The mass extinction 250 million years ago that changed the face of life on Earth is looking even more devastating as a pack of killers is invoked to explain the mayhem

Life is made of sturdy stuff. A good thing, too, since living creatures have had a rough time of it these past 545 million years. In that time at least five mass extinctions have wracked the biosphere, wiping out major portions of existing species and allowing the survivors to reshape the biological world. While the death of the dinosaurs and the loss of upward of 50% of other species 65 million years ago at the boundary of the Cretaceous and Tertiary periods is the best known extinction, it is by no means the greatest.

In fact, the Cretaceous-Tertiary extinction was little more than a sideshow, says paleontologist Douglas Erwin of the National Museum of Natural History, compared to the devastation that occurred 250 million years ago between the Permian and Triassic periods. At the Permo-Triassic boundary, life in the sea was nearly snuffed out: At least 80%, and perhaps as much as 95%, of marine species disappeared. Life has never been the same. "The organisms you see in a tide pool today are a consequence of what happened 250 million years ago," says Erwin. "If the Permo-Triassic extinction hadn't happened the way it did, you would find a whole different bunch of beasts there."

Despite its size and importance, for many years studies of the Permo-Triassic (P-T) mass extinction lagged far behind those of the Cretaceous-Tertiary boundary. Within recent years, however, that's begun to change as more researchers have begun looking at the P-T boundary. And as the picture of the P-T extinction gets filled in, researchers are recognizing an event even more calamitous than they suspected. Recent results show more victims (insects on land in addition to devastation in the seas) and a briefer duration (shortened by half or more). Rather than indicting a single killer for this calamity, researchers are now thinking that the P-T massacre may have resulted from a fatal combination of deleterious environmental changes that add up to what Erwin calls the "world went to hell" hypothesis.

The current wave of interest in the P-T boundary began in the 1980s, triggered by the realization that the geologic record there had more to tell than had been realized. Earlier studies of the Permian period had focused on sea life as preserved in sedimentary rocks at sites from Pakistan to Greenland. These fossils showed that Permian ocean life was sparse, even sedate. Animals tended to be immobile, standing on stalks or lying on the sea floor and quietly filtering detritus for a meal or waiting for prey to come by. Snails and bivalves were a minor part of the fauna; active predators were scarce.

By the end of the 40-million-year-long Permian, says Erwin, those "well-developed ecosystems were torn apart by the extinction." In their place came a new set of communities that were more diverse. Gone were the easily preyed upon meadows of stalked animals, replaced by armored snails and deep-burrowing bivalves. Predatory free swimmers such as cephalopods and reptiles became abundant. The gigantic extinction had actually invigorated ocean life, as the few hardy survivors eventually filled more niches than the ones left by the victims.

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—Douglas Erwin

It wasn't until this year that researchers realized that history's most diverse land animals—the insects—had also suffered a major extinction between the Permian and the Triassic. This extinction is doubly notable because it is the only one in the 390-million-year history of these hardy creatures. Writing earlier this year in *Science* (16 July, p. 310), Conrad Labandeira of the National Museum of Natural History and John Sepkoski of the University of Chicago reported that buried in some of the less accessible literature—especially the older German and more recent Russian papers—is clear evidence that eight of the 27 orders of insects in the Permian did not survive into the Triassic. Another three orders struggled into the Triassic only to perish there.

Like the marine survivors, the insects that came through the P-T extinction tended to have new, more effective ways of coping with the stresses of life. Survivors were more likely to have an intermediate resting stage in their life cycle, notes Labandeira, or some other means of weathering hard times, such as protective scales or a habit of burrowing. The extraordinary surge of insect diversity that steadily carried the insects to the dominance they enjoy today was "largely attributable to the end-Permian mass extinction," which redirected insect evolution, say Labandeira and Sepkoski.

Naturally, the recognition of a major extinction among another Permian group raises the question of what caused it. But there, paleontologists have been at something of a loss. "This extinction boundary has simply elicited the reaction: 'We know there's an extinction and it's mysterious,'" says paleontologist David Bottjer of the University of Southern California. Paleontologists tended to concentrate on what life was like within a geologic period, notes Bottjer, rather than what happened at the boundaries between them. But approaches developed during the well-publicized work on the Cretaceous-Tertiary mass extinction have provided a helpful model.

That extinction was also a mystery until paleontologists, geologists, and geochemists, prompted by the discovery of traces of a huge cometary impact that might have caused it, began analyzing in minute detail the sediments laid down during the extinction. Now, at the P-T boundary, "what we're seeing is the beneficial spinoff of the [Cretaceous-Tertiary] debate," says paleontologist David Raup of the University of Chicago. "They're getting down on the ground and seeing what it's really like. It's all for the good."

One of the first fruits of that closer examination is the realization that the P-T extinction took place in a much shorter period than was thought, a finding that increases its intensity. A few years ago, the published length was 8 to 10 million years—gradual by any measure. At the time, Erwin thought 5 million years was a better estimate, but "as the data have been getting better, the extinction has appeared to get more rapid," he says.

Exactly how rapid the P-T was is still unclear, because paleontologists are struggling with imperfections in the P-T record—missing sections of the geologic record and poor fossil markers for keeping track of time—that confound efforts to calculate its apparent duration. Despite the difficulties, though, some paleontologists are claiming that at least some of the marine extinctions came in a burst right at the P-T boundary. "It was something like thousands of years, not millions, a big wipe-out,"says Anthony Hallam of the University of Birmingham. Hallam's colleague in P-T work, paleontologist/sedimentologist Paul Wignall of the University of Leeds, agrees. "In the field, it seems dramatically sudden. There may have been a decline before that, but I believe there was a sharp event at the very end of the Permian."

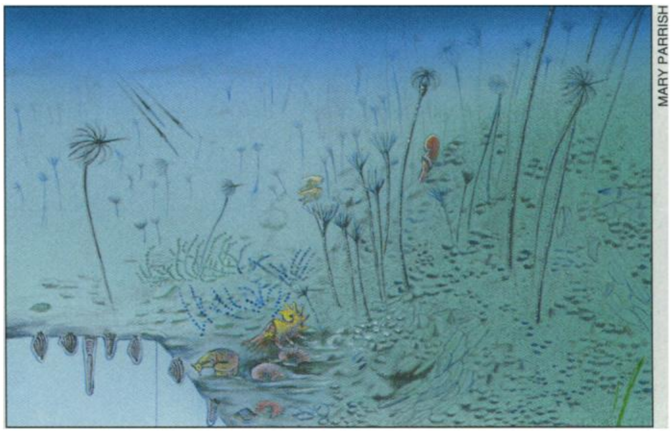
Erwin, like many of his colleagues, is open to the possibility of an abrupt pulse of marine extinctions at the P-T boundary, but he also sees a more protracted period of extinction lasting a million years or more—but still far shorter than even his 5-million-year estimate from a few years ago. Evidence from terrestrial vertebrate fossils in South Africa, including those of reptiles and amphibians, also supports the picture of a protracted extinction with a pulse at the boundary lasting about a million years or less, says paleontologist Peter Ward of the University of Washington in Seattle.

With the P-T boundary looking more and more like the site of a prolonged extinction of varying intensity, the experts are now wondering what could cause a massive event of that kind. The one thing all concerned agree on is that—despite claims to the contrary in the mid-1980s—there is no evidence of an asteroid or comet impact having anything to do with the P-T extinction. In place of a single destructive event, researchers are now pondering the possibility that a combination of stresses might be needed to explain the massive extinctions on land and in the sea.

One long-standing proposal is that the extinction was caused when the sea level fell, perhaps as much as 150 meters, during the few million years before the P-T boundary, laying bare most continental rock. While that was a slow decline, it could have produced dramatic climate changes. At the time, all the continents were fused in a single supercontinent, Pangaea, that was 40% covered by water. Because of water's great capacity for absorbing heat, the supercontinent would have experienced few sharp climatic swings. What's more, the high sea level also created an enormous area within the inland seas and on the continental shelf around the edges of Pangaea in which Permian shallow-water communities like reefs flourished.

Life was good in the Permian, the theory goes, until the sea went out. When sea level dropped, the swings from one season to another would have become much more extreme. Increased seasonality of this kind could have been just the sort of change that drove the insect extinctions near the P-T boundary, Labandeira says. And the dwindling area of shallow water could have driven to extinction many marine species, such as the corals that began to decline well before the boundary.

If the recession of sea level wasn't devastating enough to trigger a mass extinction by itself, researchers have lately added another possible cause: volcanic eruption. And not just any volcanic eruption, but the one that produced the Siberian Traps, a frozen puddle of at least 2 million cubic kilometers of lava that flowed across northern Siberia in a million years or less. (For comparison, Mount St. Helens' 1980 eruption drew on a mere 1 cubic kilometer of magma.) Within the limits of accuracy of isotopic dating, it appears that this enormous eruption, the largest of the past 545 million years, coincided with the P-T mass extinction. Another large eruption, which formed the Deccan Traps of India, immediately preceded the Cretaceous-Tertiary boundary (*Science*, 14 June 1991, p. 1496).



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A sea change. Survivors from the Permian oceans *(top)* eventually became members of a more mobile, more predatory world *(bottom)*.

"It would be irresponsible to ignore the possibility" that the eruption of the Siberian Traps was involved in the extinction, says Gerry Czamanske of the U.S. Geological Survey in Menlo Park, who has worked on the Siberian Traps, although he notes that its precise involvement remains speculative. Perhaps it spewed enough debris to block out sunlight and trigger an ice age, enough sulfuric acid to acidify the oceans, or enough carbon dioxide to fuel greenhouse warming.

To round out the witch's brew of killing agents, Hallam and Wignall are diagnosing their abrupt marine extinctions at the P-T boundary as a case of suffocation. Hallam and Wignall see signs in the sediments that after the sea level slowly dropped, the sea rushed back onto the continental shelves faster than it did in any other marine transgression of the past 545 million years. What caused the sea to rise tens of meters in only some thousands of years "is a problem, a puzzle," notes Hallam, "but the evidence for a global rise at this time is overwhelming."

Whatever caused the rapid return of the sea, chemical traces in the sediments laid down by the rising waters suggest that they were low in oxygen or lacking it altogether, say Hallam and Wignall. Stagnation in the deep sea can build up such anoxic waters, and when a rising sea lifts them onto the continental shelf, they would snuff out the traces of life left after any regression.

Hallam and Wignall's scenario of death by suffocation got a boost this summer when Y. Isozaki of the Tokyo Institute of Technology reported at a Pangaea meeting in Calgary that he had confirmed the likely source of their anoxic waters. Isozaki has found a 50-million-year slice of the deep-sea sedimentary record containing the P-T boundary that was plastered onto Japan. Its chemical composition shows oxygen levels in the deep-sea falling over millions of years until anoxia sets in. At that point, most Permian microplankton called radiolarians disappear, and after the worst of the anoxia Triassic ones appear. That seems to tie this exceptional episode of intense anoxia to the P-T boundary in the deep sea and, through Hallam and Wignall's rapid transgression, to the pulse of extinction in shallow waters.

Erwin takes all this in and concludes that the P-T "extinction is not a single event" with a single cause. He sees an unusual convergence of events—possibly including gradual regression of the sea, volcanic eruption, and rapid transgression of oxygen-depleted water—that makes for a uniquely devastating extinction. But all the possible causes are not yet tightly tied to the known effects, he says. Those little beasts in the tide pool have more secrets to divulge.

–Richard A. Kerr

Additional Reading

Erwin, D. H., *The Great Paleozoic Crisis: Life and Death in the Permian* (Columbia University Press, New York, NY, 1993).