K-T BOUNDARY

New Way to Read the Record Suggests Abrupt Extinction

By now, almost all researchers agree that a huge asteroid or comet struck the Yucatán Peninsula 65 million years ago, just at the moment of one of the largest mass extinctions of all time. But did the impact wipe out all those species in one blow? Or were most of them dying out long before, with the impact providing, at most, the coup de grâce? Many paleontologists have long been skeptical about the importance of the impact because—except for a few striking cases—much of the fossil record has revealed a pattern of gradual extinctions, with one species after another petering out over hundreds of thousands or even millions of years, usually before the impact. Even the extinction of the dinosaurs, the archetypal victims of the Cretaceous-Tertiary extinction, could not be tied to the impact to everyone's satisfaction.

Now a combination of more data and a new way to read between the lines of the incomplete fossil record is lending support to the impact-extinctions link. Even some doubters are finding more and more species that survived until the time of the impact. And on page 1360 of this issue of *Science*, paleontologists Charles Marshall of the University of California (UC), Los Angeles, and Peter Ward of the University of Washington analyze the fossil record with a statistical technique that can close the gap between a species's last known fossil and the actual time of its extinction. They find evidence that many of the ammonites—coiled-shell, predatory sea creatures that had seemed to die out slowly before the impact—actually met an abrupt end. Some ammonite species did die out gradually in the 2 million years before the impact, the analysis suggests, but about half if not more vanished at or very near the time of the impact. "We believe ... that it was a sudden, complete catastrophe" at the Cretaceous-Tertiary boundary, says Ward.

"I pay a lot of attention to these sorts of analyses, which are very few," says paleontologist Michael Foote of the University of Chicago. He notes that the few other efforts to take the fossil record's incompleteness into account have also "shown some combination of background extinctions and sudden extinctions at the end of the Cretaceous. At this point, I find that to be the most convincing scenario. Hopefully, it will sink in on people that this [statistical technique] is a better approach than taking the data at face value."

A literal reading of the fossil record was the standard back in the mid-1980s when Ward began collecting ammonite fossils near Zumaya in northern Spain on the Bay of Biscay. In a 1986 paper, he reported that Zumaya ammonites disappeared gradually, one after another over more than 120 meters of rock, or more than a million years. And there was a gap of 12.5 meters—roughly 125,000 years—between the last ammonite and the thin layer of impact debris above it that marks the end of the Cretaceous.

W. ZINSMEISTER/PURDUE UNIVERSITY

Hunting extinctions. Ammonite fossils found on Seymour Island off Antarctica could help determine who fell victim to the impact 65 million years ago at the end of the Cretaceous.

Ward concluded that the ammonites gradually went extinct well before the impact, but he soon changed his mind. As paleontologists Jere Lipps of UC Berkeley and Philip Signor warned in a 1982 paper, the last known appearance of a fossil species never captures the very last animal to survive. There are always more fossils waiting to be found above the last known one, and this is especially true for rare species. Indeed, as Ward searched additional fossil-rich outcrops near Zumaya, the ammonite-impact gap closed from 12.5 meters to a few centimeters, and 12 of 28 species of ammonites survived to the last 1.5 meters—perhaps 15,000 years—of the Cretaceous. The dinosaur and plant extinctions in the western interior of North America also became more abrupt as paleontologists searched the rock record more intensively (*Science*, 11 January 1991, p. 160).

But even intensive fossil hunting can't pinpoint the moment of extinction. Now Marshall and Ward think they have a way to read the fossil record that gives a better fix on the timing and can distinguish gradual extinctions from abrupt ones. "We're finally getting some quantitative rigor" in the analysis of extinctions, says Ward. The rigor comes from a statistical method refined by Marshall that takes into account a fossil's abundance in the record and thus its chance of being found, and so can quantitatively estimate the predicted gap between the last known fossil and the species's extinction.

For example, Ward found the last fossil of the ammonite *Pseudophyllites indra* 25 centimeters below the impact layer, but the abundance of its fossils up to that point shows that the best estimate for the time that it went extinct is in rock 7 centimeters above that layer. Repeat that calculation for a number of ammonites, and the estimated extinction points will bracket the time of their true demise, explains Marshall.

Applied to the late Cretaceous animals at Zumaya, the method yields a mixed picture. Of 28 ammonite species found there in the 2 million years before the boundary, six clearly disappeared before the impact in a random fashion that looks like the background extinctions that go on all the time, says Marshall. More ammonites, perhaps as many as 10, went out 10,000 to 20,000 years before the impact during a 50,000-year interval of low sea level, which may have triggered their demise. And six species of bivalve mollusks called inoceramids also went out gradually about 1.5 million years before the impact, perhaps because of global changes in deep-sea circulation.

Still, Marshall and Ward find far more action at or near the impact. The most likely explanation for the distribution of fossils in the last 1.5 meters before the impact is that at least 12 of the 28 ammonite species and one inoceramid went extinct at the impact itself, says Marshall. "We can never actually prove" that they died out at that instant, he explains. "If we could find a hundred times more fossils, we might find there was an actual gradual extinction over the last few centimeters of the Cretaceous." But any such "gradual" disappearance must have been on the order of 1000 years, he says—which is abrupt by the standards of geologic time.

To some paleontologists, the new statistical results shore up the idea of a catastrophic extinction. Karl Flessa of the University of Arizona had already found the accumulating raw data from the Bay of Biscay to be "one of the more compelling stories" of the Cretaceous-Tertiary extinction, especially because the ammonites had been thriving for 350 million years and had managed to survive an even worse extinction at the end of the Permian period. Now that the coincidence of the impact and ammonite extinctions has been quantified, it looks "like things are falling into place" for an impact-driven extinction at the end of the Cretaceous, he says.

Norman MacLeod of The Natural History Museum in London is less sanguine, noting that while the statistics are "consistent" with an impact, they are also consistent with a more drawn-out decline on the same order of time as the disappearance of the mammoths. "A lot of things—climatic cooling, a sea-level fall, and probably volcanic activity—were coming together at the end of the Cretaceous. The ammonites [could have] started crashing 5000 years before the meteorite arrived. That's still enough time" for other extinction mechanisms to work, he says.

And of course, the Bay of Biscay alone won't resolve the fate of all ammonites, much less Cretaceous life in general, around the globe. "It's an exemplary study," says David Jablonski of the University of Chicago, but what's needed is to "expand the geographic and taxonomic coverage."

Broader geographic samples are beginning to come in, and the gap between the last fossil and the impact debris layer is shrinking elsewhere too. For example, far to the south of Zumaya, the Cretaceous ammonites of Seymour Island off Antarctica have fueled the extinction controversy since the late 1980s, when William Zinsmeister of Purdue University and his colleagues concluded that the ammonites and other large marine animals there petered out over 50 meters of sediment—well before the impact. Using these fossils and other evidence from tiny, shelled marine plankton called forams, Zinsmeister, MacLeod, and others had argued that while a few extinctions in some parts of the tropics may have been catastrophic, animals at high latitudes suffered less or not at all at the time of the impact.

Now Zinsmeister is shifting his stance in the light of additional field collecting on Seymour Island. The new data, which he presented at last month's meeting of the Geological Society of America, imply that "the changeover is much more abrupt then we said earlier," he says. Still, Zinsmeister is not yet so impressed by Marshall's statistical method as to suggest that most species went out precisely at the impact. He and his crew searched the vicinity of the impact layer intensively last field season—and found no ammonites. So he suspects that many species went extinct under the environmental stresses of the late Cretaceous, and then "along came Big Bertha and that was it." The idea of the impact as merely the final stroke for a few stragglers, rather than a principal trigger, has many supporters. It may take a pile of statistical readings, from many different pages of the fossil record, to change the minds of paleontologists.

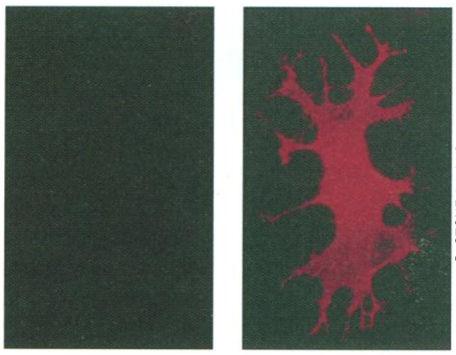
–Richard A. Kerr

DEVELOPMENTAL BIOLOGY

Hedgehog's Patterning Call Is Patched Through, Smoothly

In the parlor game Telephone, Alice whispers something to Bob, who transmits it to Carol, and so forth until a hilariously skewed message emerges at the far end of the chain. Cells in a developing embryo trade news that shapes their fates in much the same way, with extracellular growth factors, cell-surface receptors, and intracellular courier molecules acting as go-betweens. But in one important kind of phone call between cells, involving the powerful Hedgehog (Hh) family of pattern-forming proteins, a key party has long been hidden—the receptor on the cell surface. As a result, researchers couldn't tell where the message went after reaching the cell or why it is sometimes dangerously distorted, spurring cancerous cell proliferation.

Now the mystery party has been unmasked, revealing not one molecule but a dynamic duo. The receptor molecule for the vertebrate protein Sonic hedgehog (Shh)—which transmits a signal that can help embryonic hands tell thumb from little finger, for example—is a membrane-bound protein called Patched (Ptc), according to two reports in the 14 November issue of *Nature*. But Ptc itself doesn't transmit the signal to the cell interior; instead, these reports and other recent work suggest that its usual job may be to interrupt signaling by another molecule called Smoothened (Smo). Shh's arrival distracts Ptc from this job, allowing Smo's message to get through.



D. STONE, W. ANSTINE, A. ROSENTHAL

Smoothed out. The signaling molecule Sonic hedgehog binds to embryonic cells expressing the protein Patched (red stain, *right*), but not to cells expressing another receptor candidate, Smoothened *(left)*.

Molecular biologist Norbert Perrimon of Harvard Medical School says "there is no precedent" for this arrangement in the annals of cell biology, and notes that it helps explain data that last summer led some researchers to finger Smo itself as the Shh receptor. The work may also help researchers understand why mutations in the gene encoding Ptc predispose some people to a common skin cancer. Neurobiologist Doros Platika, chief executive officer of Ontogeny Inc. of Cambridge, Massachusetts, which has an exclusive license to develop medical therapies using Shh and Ptc, is already thinking about possible treatments for such cancers. "We're delighted with this news," he says.

Developmental biologists have long known that Hh shuttles signals from cell to cell in fruit fly embryos, directing them to carry out tasks such as setting up repeated body segments or organizing eyes, wings, and limbs. In vertebrates, Shh and its cousins play similar roles, lending pattern to bone, muscle, and neurons. But until recently, no one knew the identity of the Hedgehog proteins' receptor. Although the overlapping distribution of Hh, Ptc, and related proteins in fly embryos led geneticist Phil Ingham of the Imperial Cancer Research Fund in Oxford, England, to propose in 1991 that Ptc is the Hh receptor, his lab lacked the biochemical facilities to test whether the two molecules actually bind to each other. Then, this summer, experiments in Ingham's lab and in the labs of molecular biologists Markus Noll at the University of Zurich in Switzerland and Joan Hooper at the University of Colorado showed that Smo has a chemical structure typical of a receptor, and that mutant flies with defective Smo can't respond to Hh signals. That persuaded most researchers that Smo was a better candidate than Ptc.

But now it seems that Ingham's first guess was right. A group led by Arnon Rosenthal, a molecular neurobiologist at San Francisco's Genentech Inc., reports in *Nature* that mouse Shh doesn't bind biochemically to cells producing the mouse version of Smo, but does bind to cells making mouse Ptc. A second group, led by Harvard Medical School developmental geneticists Valeria Marigo and Cliff Tabin, boosted the case by injecting messenger RNA encoding Ptc into *Xenopus* frog eggs, which lack natural Ptc at this stage. Shh bound to the injected eggs but not to unaltered eggs, further showing that Ptc can scoop up Shh in living cells. The team also demonstrated that their experiments were mimicking true biological conditions by showing that the binding between Ptc and Shh could be blocked with an antibody known to interfere with Shh's signal in living tissue.