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Why Did Ferns Persist When All Other Plants Perished?

A strange layer in the fossil record contains evidence that fern populations exploded following the mass extinction that ended the Cretaceous period. Scientists want to know why.

Amanda Heidt
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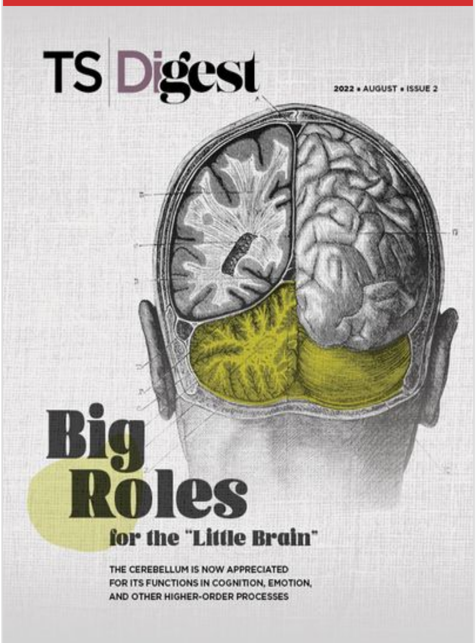
ABOVE:
Ferns bounced back much faster than other plants after the meteor impact that wiped out the dinosaurs.

It was likely a warm spring day in the Northern Hemisphere when the dinosaur-ending asteroid careened into Earth some 65 million years ago, according to scientists' latest hypothesis. In the ensuing firestorm and the so-called impact winter that followed, the lush and towering coniferous forests that had marked the Cretaceous disappeared, and for roughly a decade, there was only cold and darkness. Even after light returned, it took thousands of years for life to claw its way back, ushering in a new age dominated by the mammals and flowering plants of today.

Scientists can readily detect this Cretaceous-Paleogene (K-Pg or K-P) mass extinction in the geological record thanks to a thin layer of pale stone enriched in iridium, a chemical element released during asteroid impacts, that separates the rock from the two periods. But since the 1970s, geologists have also noted the existence of another layer, just above the iridium-rich one, that contains "lots and lots and lots of fossil fern spores" and not much else, says Ellen Currano, a paleobotanist at the University of Wyoming. "We see very few conifers or angiosperms or anything like that," she adds, leading researchers to dub the layer the fern spike.

Ferns aren't any better preserved in the fossil record than other types of plants, and so their explosion in abundance in the centuries following the asteroid's impact suggests that "something about ferns means they did well in those conditions," Currano says. Several hypotheses have been bandied about to explain the spike. Ferns are hardy, often the first to pierce lava fields, for example, while their spores—which are smaller than dust and capable of dispersing across vast distances—can remain dormant for decades. And unlike many trees, which can't grow back from only their roots, ferns spring back following above-ground damage thanks to underground stems called rhizomes, which may have been insulated from surface firestorms. Despite these suppositions, "nobody ever bothered to figure out, from the biological side, what the spike was all about," says University of Florida plant evolutionary biologist Emily Sessa.

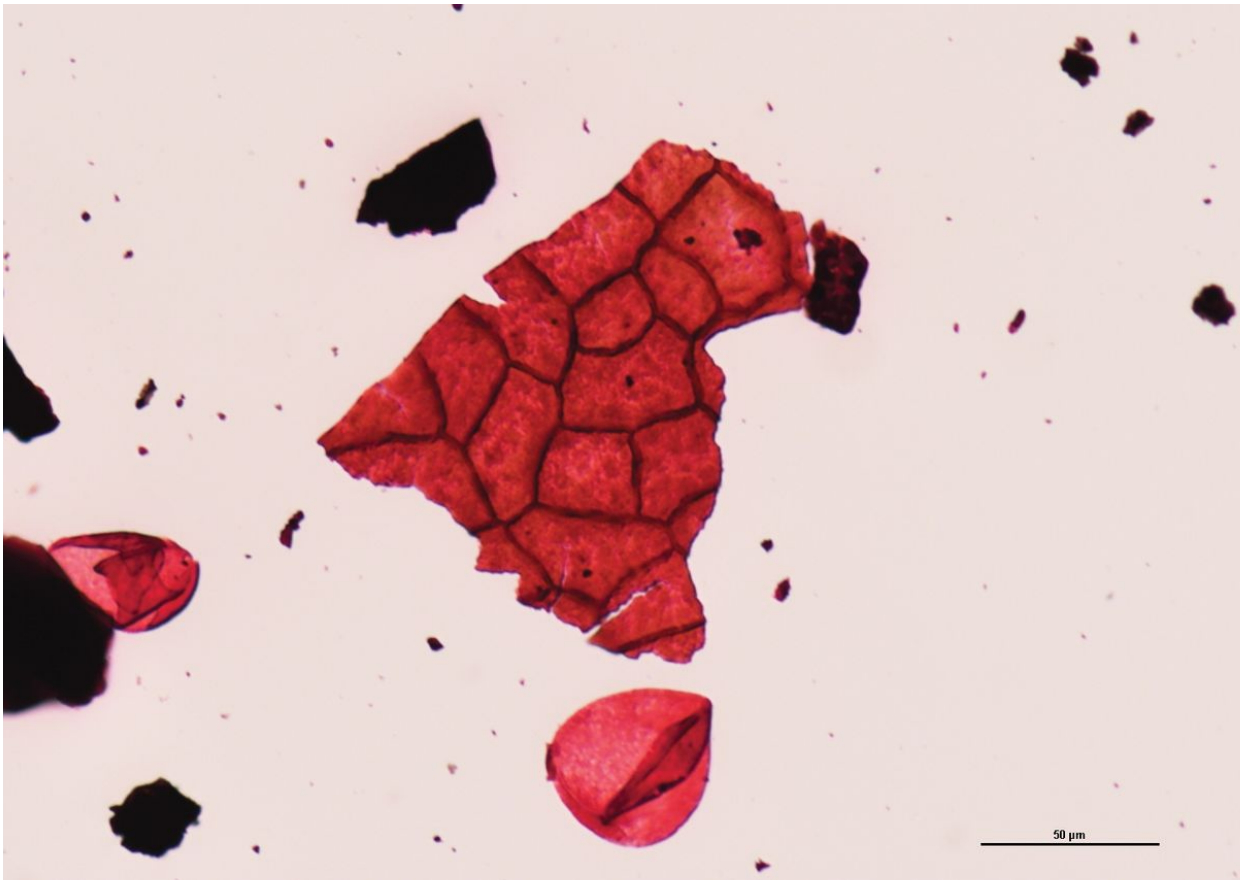


Now, at last, Sessa, Currano, and their colleagues may have the chance to do so. In 2019, NASA funded the group's research proposal as part of the agency's interest in exploring how organisms respond to extreme environments, including those that occurred during Earth's mass extinctions. Sessa and Jarmila Pittermann, a plant ecophysiologist at the University of California (UC), Santa Cruz, are using a greenhouse to create Cretaceous-like conditions and, at some point, will set off a simulated meteor impact. The unsuspecting plants inside include angiosperms, gymnosperms, and ferns in both of the plants' life stages: the large, recognizable sporophyte and the much smaller, mosslike gametophyte. In tandem, Currano and Regan Dunn, a paleoecologist at La Brea Tar Pits and Museum in Los Angeles, are mining museum specimens and traveling to well-known K-Pg sites in Colorado, Montana, and Wyoming to compare the greenhouse plants to fossilized fern leaves and spores from the time of the iridium anomaly and the fern spike.

The halcyon days of this mini-Cretaceous are numbered.

"Broadly speaking, there's three ways to study the past: You can read directly from the fossil record, you can search for contemporary analogs in the world around us, or you can use an experimental approach . . . to simulate the event," says Jonathan Wilson, a paleobotanist at Haverford College in

Pennsylvania who previously collaborated with Pittermann but is not involved in the current work. This project, he says, “is such a novel approach to a big event like this” because it involves all three. “I think this will help us set the field for future experiments.”



Micrograph of a fragment of leaf cuticle showing epidermal cells (clustered) and a fern spore (bottom center) from a K-Pg site in southern Colorado

REGAN DUNN

The project has had a few hiccups so far. The equipment can be finicky, Pittermann tells *The Scientist*, and the work was delayed for a year by the COVID-19 pandemic, when campuses closed down and it became challenging to source plants and other materials. Even today, with the work well underway, “it’s all just hoping that nothing goes wrong, that the equipment doesn’t break, that the plants don’t overheat,” Pittermann says. “Those are the kinds of things that keep me up at night—literally just the practical aspects.”

Reconstructing the environmental conditions pre asteroid impact has also taken time, and a vast trove of paleoclimate literature. For now, Pittermann is growing the plants in the Santa Cruz greenhouse at roughly 25 °C during the day and 17 °C at night, keeping the humidity high, and holding the carbon dioxide at 1,000 parts per million. This first phase has now been running for several months, and the team recently collected its first batch of data, including the timing and extent of spore germination, plant growth, cell morphology, and metabolites.

The halcyon days of this mini- Cretaceous are numbered, of course. Soon, the asteroid will strike. The greenhouse will be covered with tarps to block out most of the light, and the temperature will plummet to below 10 °C. A lab technician will periodically paint the plants' leaves with a dilute solution of sulfuric acid to mimic acid rain. (The team can't risk the sensitive monitoring equipment being damaged by misting, so it will all have to be done by hand, Pittermann explains.) Sessa is running a similar experiment in growth chambers at her lab in Florida focusing on the smaller gametophytes.

Meanwhile, Currano and Dunn will use their combined expertise to link the results with what is visible in the fossil record. Currano has been pulling rare fossils of fern leaves from museum collections to compare with the greenhouse samples, while Dunn is using a proxy she previously developed based on microscopic analyses of leaf morphology to estimate the amount of light a fossilized plant received when it was alive. The results are preliminary, but Dunn tells *The Scientist* that her approach does seem to register changes in canopy light levels from just before the iridium-rich layer to just after it, a pattern that could be consistent with the ecological effects of an impact.

Ellen Currano and Alex Baer inspect plants in a greenhouse at the University of California, Santa Cruz.
REGAN DUNN

Jeffrey Benca, an experimental paleobotanist at UC Berkeley, says that the project sounds extremely challenging. While not involved in this research, Benca spent years preparing his own extinction experiment, which focused on the world's largest known mass extinction: an event that took place around 250 million years ago called The Great Dying. Prior to starting his experiment, Benca challenged bonsai conifers with stressful conditions—full sun, low nutrients, and very little soil—for a year to prepare them to weather months of "UVB radiation that would probably kill most aquatic organisms in minutes," to determine whether ozone degradation following volcanic eruptions might explain an odd pattern of misshapen pollen in the fossil record. He found that the radiation didn't just malform the pollen, it sterilized the trees, potentially killing off entire forests.

Benca says he wonders how the team studying the asteroid impact will tease apart the effects of so many variables. He altered only a single parameter, UV exposure, in his study to be sure he could identify a clear cause. "Once you get into the realm of having to test multiple variables, it gets a lot harder to figure out what's actually causing the signal and what variables are really important," he says.

There's the additional consideration that, even though ancient plant lineages persist today, it's not clear whether greenhouse plants will react as their predecessors would have 65 million years ago. However, researchers who spoke to *The Scientist* think that the fundamental aspects of plant biology, including that of ferns, have remained largely fixed since the Cretaceous. "When you look at something like the K-P, it's actually an ideal event to study because we feel like we know the cast of characters," Wilson says. "So it's particularly amenable to this kind of approach."

The work could one day aid NASA scientists considering extraterrestrial aims: If ferns are hardy enough to survive one of the five largest mass extinctions, they might also be a first step toward terraforming Mars, for instance. The project could also do much to illuminate fern biology, about which so little is known. "In general, if you ask any kind of question you can imagine about plant ecology or evolution, chances are the answer in ferns is, 'We don't know' or 'We need to know more,'" Sessa says. "That's made them a really fun group to work on."

ANDRZEJ KRAUZE