Amid a fossil bonanza, drilling deep into pre-dinosaurian rocks

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The landscape at various times consisted of shallow seas, rivers and swamps. Repeating bands of color may represent climate shifts caused by cyclic changes in earth's orbit, or other factors such as tectonic movements. Within these rocks lie what may be the world's richest beds of fossils from the late Triassic. Climate changes almost certainly affected the course of life.

On a high ridge in Arizona's Petrified Forest National Park, paleontologist Paul Olsen sits on the fallen trunk of a 215-million-year-old tree, now turned to stone. The tree once loomed 70 or 80 feet above a riverine landscape teeming with fish, turtles, giant crocodilians and tiny, early species of dinosaurs. From here, Olsen can survey the remnants of this lost world: miles and miles of surreal badlands, where sediments built up over millions of years have eroded back down to expose endless cross sections of brightly colored rocks. The layers represent tectonic movements, natural climate cycles, the growth and disappearance of lakes, buildups of river deltas. The petrified trees scattered across the landscape are only the most obvious fossils; others are bleeding out by the ton. It is perhaps the world's richest trove of rocks from the late Triassic, when dinosaurs, and early mammals, got their evolutionary start. The Triassic was also a hothouse world: a time of high atmospheric carbon dioxide, rapid climate shifts, and fast-moving extinctions. Olsen thinks there may be much to learn from it for our own time.

Scientists have been digging here since the 1850s, yet much remains unknown about the exact timing of events in the late Triassic, between about 235 million and 201 million years ago. That is why Olsen is here. He is co-leader of a team that is drilling a borehole deep into the rocks. By taking out a continuous core–a first for this region–they hope to assemble a record that will not only help them write a reliable history for this pivotal time, but shed light on how natural climate cycles work, and how they affect ecosystems–knowledge that, among other things, should advance scientists' ability to assess the prospects for human-induced shifts.

"Even in this area of beautifully outcropping rocks, it's hard to put together an exact sequence of events, based on what you see," says Olsen, sweeping his hand over the vast maze of buttes, mesas, canyons and pinnacles. Deeper layers are inaccessible from the surface, and erosion has carried away elements from many shallower ones, making it impossible to see exactly how they relate to each other, and when each was formed. A continuous core will provide "an unimpeachable record," he says. Because of the richness of fossils and the large number of studies that have already been done, he says, "This is one place in the world, where by resolving exact times of events, we can ask very specific questions about how earth's systems work. Understanding ancient environments gives us strong clues to future ones. In fact, it's the only way to test our climate models. Other than letting the experiment [in global warming] we are in right now to run its course. I think we'd like to know that with a little more certainty."

Olsen, a Columbia University professor and researcher at the university's Lamont-Doherty Earth Observatory, thinks all kinds of questions can be answered here. For one, the core should allow scientists to figure out the timing of repeated shifts in temperature and precipitation caused by periodic shifts in earth's orbit, and whether such shifts operated on the same schedule during the Triassic as they have in more recent times. These cycles have been documented by Olsen and his colleagues in Triassic-age rocks of the Newark Basin, near New York City–but those rocks don't contain certain minerals that allow the cycles to be placed in absolute time. The ones at Petrified Forest do. "If we can show that the Newark timescale is correct, we can empirically calibrate the solar system's behavior," Olsen told the journal *Nature* in an article about the project. A more specific question: whether a giant meteorite that left a crater more than 50 miles wide in what is now Quebec had anything to do with a large turnover in flora and fauna during the Triassic. The crater is precisely dated, at 215.5 million years, but the turnover is not; estimates vary by 10 million years or more. If there is a direct connection, Olsen suspects it can be made by dating what he calls an "extinction layer" that outcrops in various parts of the park, where the sediments suddenly change to red and white, and fossils practically disappear, suggesting some kind of catastrophe.

Despite all the easily visible geology, many formations have been disarranged by uneven erosion. This makes it hard for scientists to write a cohesive history of the time. By taking out a continuous record from one or more spots, the coring project is aimed at establishing a reliable chronology.

Near where Olsen is sitting, on the edge of a nearby butte, a three-man crew is running a roaring diesel-powered drill. Its hollow-tip bit is boring at 1,000 revolutions per minute through one formation after another at a 30-degree angle, 24 hours a day, seven days a week. About every 20 or 30 minutes, the crew hauls out a casing containing a five-foot length of core. Geologists working with Olsen take turns carrying the plastic-swathed core to a tent, labeling it, cutting it into half-sections and piling it in the back of pickup truck. Depending on the layer, the drill brings up mudstones or siltstones in shades of purple, red and brown; some are flecked with gray or white carbonates, and occasionally squiggles that look like they could be fossilized tree roots, or streambed ripples. At one point, the drill hits an unknown obstruction that causes it to veer off course–possibly a fossilized tree, made of extremely hard quartz. Their straight course compromised, the drillers have to pull out and start again.

The $970,000 project is a collaboration among Lamont, Rutgers University, the universities of Arizona, Texas and Utah, and other institutions. The drilling, which took place in November and December 2013, took nearly a month, bottoming out at 1,706.5 feet in one hole, then at 830 feet in a second. The deeper hole appears to reach back at least 250 million years–the very start of the Triassic. In coming months, the cores will be examined at various labs using CAT scans, chemical analyses, magnetism and high-resolution photography.

Ashes from repeated volcanic eruptions are known to punctuate the sedimentary layers, and those ashes contain mineral grains with radioactive isotopes that can be analyzed to yield absolute ages. Also, sporadic reversals in earth's magnetic field are recorded in the orientation of grains within the sediments themselves. Lamont paleomagnetics expert Dennis Kent will try to line up these reversals with the volcanic layers. Project co-leader John Geissman, a geologist at the University of Texas, Dallas, says, "It's a unique opportunity to put together a coherent time framework for a critical [time]." The team hopes this will be the first of a half-dozen sites in a proposed wider study dubbed the Colorado Plateau Coring Project. This is aimed at studying the Four Corners region spanning Colorado, Arizona, Utah and New Mexico, which shares many of the same rock formations.

In backcountry places known only to Parker and colleagues, fossils of every description are lying right on the surface, eroded from decaying rocks. Here, skull fragments and a tooth, perhaps from a phytosaur, another reptile once common here; more fragments lie on the ground.

One thing the new core will not address: the apparent sudden mass extinction that ended the Triassic, recently dated to 201.6 million years ago. Rocks from that time have already been washed away from the park, but Olsen and Kent are investigating the end-Triassic elsewhere, from the Newark Basin to the United Kingdom and Morocco. It was that extinction–possibly caused by massive volcanic eruptions, or another meteorite–that cleared the way for the dominance of dinosaurs, who were up until then only a minor group. The remains of dinosaurs themselves are seen in only a few early forms around Petrified Forest. These include one early type, the Chindesaurus–a vaguely lizardlike, possibly feathered, creature that measured around 6 feet long, and probably ran around on two legs chasing after smaller animals to eat. It was first discovered in 1984 near the drill site.

Most other animal fossils are non-dinosaurs like those of the Revueltosaurus, one of many large reptiles that walked the land, or slithered through shallow waters covering the region during much of the period. Revueltosaurus, at first known mainly through fragments such as teeth, was in fact long thought to be a type of dinosaur. But the first intact skeleton, unearthed at Petrified Forest in 2005, upset ideas about dinosaur evolution by showing it was actually more related to modern crocodiles–a whole other line. Bill Parker, the park paleontologist, has since dug up a trove of their skulls. In some locales, pieces of them and their contemporaries are so common, they can be scooped by the handful right off the surface–eye sockets, vertebrae, teeth, fragments of limbs, fish scales. Some cliff faces seem entirely made of clams.

The team's drill--here seen at sunset--has been planted at the edge of a butte. The crew runs it in shifts 24 hours a day. The monthlong drilling is supervised by a consortium of scientists from different universities, and funded by the National

Science Foundation, The borehole will eventually bottom out at 1,706.5 feet.

"OK, basically right where you're standing on, you're standing on a bunch of bone fragments, and coprolites [fossilized feces] that are coming out of this layer," Parker tells a visitor at a backcountry site he has worked on. With thumb and forefinger, Parker picks out a thumb-size fossil poop maybe 223 million years old from the loose surface. "And right here … that's a tooth. That's a phytosaur tooth," he says, pulling out a nasty triangular thing evidently made for tearing apart flesh. How some creatures disappeared and others took over, whether through sudden shifts in climate or otherwise, is a prime question for Parker and others. They see rising modern extinctions and prospective climate change as an analog.

"When I first started working here, the story was that there was a forest here, and some dinosaurs running around," says Parker. He thinks this is hopelessly oversimplified. "That's like saying, the Battle of Gettysburg was some guys with guns on one side, shooting at guys with guns on the other side. That doesn't tell you anything about history itself. The goal here with the coring is to tell the story of 20 million years, almost millennium by millennium. It we can put together a really good picture of what happened then, we might even learn about things that are of concern to people today."

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