

THE DAY THE DINOSAURS DIED

A young paleontologist may have discovered a record of the most significant event in the history of life on Earth.

By Douglas Preston

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If, on a certain evening about sixty-six million years ago, you had stood somewhere in North America and looked up at the sky, you would have soon made out what appeared to be a star. If you watched for an hour or two, the star would have seemed to grow in brightness, although it barely moved. That's because it was not a star but an asteroid, and it was headed directly for Earth at about forty-five thousand miles an hour. Sixty hours later, the asteroid hit. The air in front was compressed and violently heated, and it blasted a hole through the atmosphere, generating a supersonic shock wave. The asteroid struck a shallow sea where the Yucatán peninsula is today. In that moment, the Cretaceous period ended and the Paleogene period began.

A few years ago, scientists at Los Alamos National Laboratory used what was then one of the world's most powerful computers, the so-called Q Machine, to model the effects of the impact. The result was a slow-motion, second-by-second false-color video of the event. Within two minutes of slamming into Earth, the asteroid, which was at least six miles wide, had gouged a crater about eighteen miles deep and lofted twenty-five trillion metric tons of debris into the atmosphere. Picture the splash of a pebble falling into pond water, but on a planetary scale. When Earth's crust rebounded, a peak higher than Mt. Everest briefly rose up. The energy released was more than that of a billion Hiroshima bombs, but the blast looked nothing like a nuclear explosion, with its signature mushroom cloud. Instead, the initial blowout formed a "rooster tail," a gigantic jet of molten material, which exited the atmosphere, some of it fanning out over North America. Much of the material was several times hotter than the surface of

the sun, and it set fire to everything within a thousand miles. In addition, an inverted cone of liquefied, superheated rock rose, spread outward as countless red-hot blobs of glass, called tektites, and blanketed the Western Hemisphere.

Some of the ejecta escaped Earth's gravitational pull and went into irregular orbits around the sun. Over millions of years, bits of it found their way to other planets and moons in the solar system. Mars was eventually strewn with the debris—just as pieces of Mars, knocked aloft by ancient asteroid impacts, have been found on Earth. A 2013 study in the journal *Astrobiology* estimated that tens of thousands of pounds of impact rubble may have landed on Titan, a moon of Saturn, and on Europa and Callisto, which orbit Jupiter—three satellites that scientists believe may have promising habitats for life. Mathematical models indicate that at least some of this vagabond debris still harbored living microbes. The asteroid may have sown life throughout the solar system, even as it ravaged life on Earth.

The asteroid was vaporized on impact. Its substance, mingling with vaporized Earth rock, formed a fiery plume, which reached halfway to the moon before collapsing in a pillar of incandescent dust. Computer models suggest that the atmosphere within fifteen hundred miles of ground zero became red hot from the debris storm, triggering gigantic forest fires. As the Earth rotated, the airborne material converged at the opposite side of the planet, where it fell and set fire to the entire Indian subcontinent. Measurements of the layer of ash and soot that eventually coated the Earth indicate that fires consumed about seventy per cent of the world's forests. Meanwhile, giant tsunamis resulting from the impact churned across the Gulf of Mexico, tearing up coastlines, sometimes peeling up hundreds of feet of rock, pushing debris inland and then sucking it back out into deep water, leaving jumbled deposits that oilmen sometimes encounter in the course of deep-sea drilling.

The damage had only begun. Scientists still debate many of the details, which are derived from the computer models, and from field studies of the debris layer, knowledge of extinction rates, fossils and microfossils, and many other clues. But the over-all view is consistently grim. The dust and soot from the impact and the conflagrations prevented all sunlight from reaching the planet's surface for months. Photosynthesis all but stopped, killing most of the plant life, extinguishing the phytoplankton in the oceans, and causing the amount of oxygen in the atmosphere to plummet. After the

fires died down, Earth plunged into a period of cold, perhaps even a deep freeze. Earth's two essential food chains, in the sea and on land, collapsed. About seventy-five per cent of all species went extinct. More than 99.9999 per cent of all living organisms on Earth died, and the carbon cycle came to a halt.

Earth itself became toxic. When the asteroid struck, it vaporized layers of limestone, releasing into the atmosphere a trillion tons of carbon dioxide, ten billion tons of methane, and a billion tons of carbon monoxide; all three are powerful greenhouse gases. The impact also vaporized anhydrite rock, which blasted ten trillion tons of sulfur compounds aloft. The sulfur combined with water to form sulfuric acid, which then fell as an acid rain that may have been potent enough to strip the leaves from any surviving plants and to leach the nutrients from the soil.

Today, the layer of debris, ash, and soot deposited by the asteroid strike is preserved in the Earth's sediment as a stripe of black about the thickness of a notebook. This is called the KT boundary, because it marks the dividing line between the Cretaceous period and the Tertiary period. (The Tertiary has been redefined as the Paleogene, but the term "KT" persists.) Mysteries abound above and below the KT layer. In the late Cretaceous, widespread volcanoes spewed vast quantities of gas and dust into the atmosphere, and the air contained far higher levels of carbon dioxide than the air that we breathe now. The climate was tropical, and the planet was perhaps entirely free of ice. Yet scientists know very little about the animals and plants that were living at the time, and as a result they have been searching for fossil deposits as close to the KT boundary as possible.

One of the central mysteries of paleontology is the so-called "three-metre problem." In a century and a half of assiduous searching, almost no dinosaur remains have been found in the layers three metres, or about nine feet, below the KT boundary, a depth representing many thousands of years. Consequently, numerous paleontologists have argued that the dinosaurs were on the way to extinction long before the asteroid struck, owing perhaps to the volcanic eruptions and climate change. Other scientists have countered that the three-metre problem merely reflects how hard it is to find fossils. Sooner or later, they've contended, a scientist will discover dinosaurs much closer to the moment of destruction.

Unearthing Black History at the Freedom Lots

Locked in the KT boundary are the answers to our questions about one of the most significant events in the history of life on the planet. If one looks at the Earth as a kind of living organism, as many biologists do, you could say that it was shot by a bullet and almost died. Deciphering what happened on the day of destruction is crucial not only to solving the three-metre problem but also to explaining our own genesis as a species.

On August 5, 2013, I received an e-mail from a graduate student named Robert DePalma. I had never met DePalma, but we had corresponded on paleontological matters for years, ever since he had read a novel I'd written that centered on the discovery of a fossilized *Tyrannosaurus rex* killed by the KT impact. "I have made an incredible and unprecedented discovery," he wrote me, from a truck stop in Bowman, North Dakota. "It is extremely confidential and only three others know of it at the moment, all of them close colleagues." He went on, "It is far more unique and far rarer than any simple dinosaur discovery. I would prefer not outlining the details via e-mail, if possible." He gave me his cell-phone number and a time to call.

I called, and he told me that he had discovered a site like the one I'd imagined in my novel, which contained, among other things, direct victims of the catastrophe. At first, I

was skeptical. DePalma was a scientific nobody, a Ph.D. candidate at the University of Kansas, and he said that he had found the site with no institutional backing and no collaborators. I thought that he was likely exaggerating, or that he might even be crazy. (Paleontology has more than its share of unusual people.) But I was intrigued enough to get on a plane to North Dakota to see for myself.

DePalma's find was in the Hell Creek geological formation, which outcrops in parts of North Dakota, South Dakota, Montana, and Wyoming, and contains some of the most storied dinosaur beds in the world. At the time of the impact, the Hell Creek landscape consisted of steamy, subtropical lowlands and floodplains along the shores of an inland sea. The land teemed with life and the conditions were excellent for fossilization, with seasonal floods and meandering rivers that rapidly buried dead animals and plants.

Dinosaur hunters first discovered these rich fossil beds in the late nineteenth century. In 1902, Barnum Brown, a flamboyant dinosaur hunter who worked at the American Museum of Natural History, in New York, found the first *Tyrannosaurus rex* here, causing a worldwide sensation. One paleontologist estimated that in the Cretaceous period Hell Creek was so thick with *T. rexes* that they were like hyenas on the Serengeti. It was also home to triceratops and duckbills.

DePalma's thesis adviser estimated that the site will keep specialists busy for half a century. "Robert's got so much stuff that's unheard of," he said. "It will be in the textbooks."

Photograph by Richard Barnes for The New Yorker

The Hell Creek Formation spanned the Cretaceous and the Paleogene periods, and paleontologists had known for at least half a century that an extinction had occurred then, because dinosaurs were found below, but never above, the KT layer. This was true not only in Hell Creek but all over the world. For many years, scientists believed that the KT extinction was no great mystery: over millions of years, volcanism, climate change, and other events gradually killed off many forms of life. But, in the late nineteen-seventies, a young geologist named Walter Alvarez and his father, Luis Alvarez, a nuclear physicist, discovered that the KT layer was laced with unusually high amounts of the rare metal iridium, which, they hypothesized, was from the dusty remains of an asteroid impact. In an article in *Science*, published in 1980, they proposed that this impact was so large that it triggered the mass extinction, and that the KT layer was the debris from that event. Most paleontologists rejected the idea that a sudden,

random encounter with space junk had drastically altered the evolution of life on Earth. But as the years passed the evidence mounted, until, in a 1991 paper, the smoking gun was announced: the discovery of an impact crater buried under thousands of feet of sediment in the Yucatán peninsula, of exactly the right age, and of the right size and geochemistry, to have caused a worldwide cataclysm. The crater and the asteroid were named Chicxulub, after a small Mayan town near the epicenter.

One of the authors of the 1991 paper, David Kring, was so frightened by what he learned of the impact's destructive nature that he became a leading voice in calling for a system to identify and neutralize threatening asteroids. "There's no uncertainty to this statement: the Earth will be hit by a Chicxulub-size asteroid again, unless we deflect it," he told me. "Even a three-hundred-metre rock would end world agriculture."

In 2010, forty-one researchers in many scientific disciplines announced, in a landmark *Science* article, that the issue should be considered settled: a huge asteroid impact caused the extinction. But opposition to the idea remains passionate. The main competing hypothesis is that the colossal "Deccan" volcanic eruptions, in what would become India, spewed enough sulfur and carbon dioxide into the atmosphere to cause a climatic shift. The eruptions, which began before the KT impact and continued after it, were among the biggest in Earth's history, lasting hundreds of thousands of years, and burying half a million square miles of the Earth's surface a mile deep in lava. The three-metre gap below the KT layer, proponents argued, was evidence that the mass extinction was well under way by the time of the asteroid strike.

In 2004, DePalma, at the time a twenty-two-year-old paleontology undergraduate, began excavating a small site in the Hell Creek Formation. The site had once been a pond, and the deposit consisted of very thin layers of sediment. Normally, one geological layer might represent thousands or millions of years. But DePalma was able to show that each layer in the deposit had been laid down in a single big rainstorm. "We could see when there were buds on the trees," he told me. "We could see when the cypresses were dropping their needles in the fall. We could experience this in real time." Peering at the layers was like flipping through a paleo-history book that chronicled decades of ecology in its silty pages. DePalma's adviser, the late Larry Martin, urged him to find a similar site, but one that had layers closer to the KT boundary.

Today, DePalma, now thirty-seven, is still working toward his Ph.D. He holds the unpaid position of curator of vertebrate paleontology at the Palm Beach Museum of Natural History, a nascent and struggling museum with no exhibition space. In 2012, while looking for a new pond deposit, he heard that a private collector had stumbled upon an unusual site on a cattle ranch near Bowman, North Dakota. (Much of the Hell Creek land is privately owned, and ranchers will sell digging rights to whoever will pay decent money, paleontologists and commercial fossil collectors alike.) The collector felt that the site, a three-foot-deep layer exposed at the surface, was a bust: it was packed with fish fossils, but they were so delicate that they crumbled into tiny flakes as soon as they met the air. The fish were encased in layers of damp, cracked mud and sand that had never solidified; it was so soft that it could be dug with a shovel or pulled apart by hand. In July, 2012, the collector showed DePalma the site and told him that he was welcome to it.

“I was immediately very disappointed,” DePalma told me. He was hoping for a site like the one he’d excavated earlier: an ancient pond with fine-grained, fossil-bearing layers that spanned many seasons and years. Instead, everything had been deposited in a single flood. But as DePalma poked around he saw potential. The flood had entombed everything immediately, so specimens were exquisitely preserved. He found many complete fish, which are rare in the Hell Creek Formation, and he figured that he could remove them intact if he worked with painstaking care. He agreed to pay the rancher a certain amount for each season that he worked there. (The specifics of the arrangement, as is standard practice in paleontology, are a closely guarded secret. The site is now under exclusive long-term lease.)

The following July, DePalma returned to do a preliminary excavation of the site. “Almost right away, I saw it was unusual,” he told me. He began shovelling off the layers of soil above where he’d found the fish. This “overburden” is typically material that was deposited long after the specimen lived; there’s little in it to interest a paleontologist, and it is usually discarded. But as soon as DePalma started digging he noticed grayish-white specks in the layers which looked like grains of sand but which, under a hand lens, proved to be tiny spheres and elongated droplets. “I think, Holy shit, these look like microtektites!” DePalma recalled. Microtektites are the blobs of glass that form when molten rock is blasted into the air by an asteroid impact and falls back

to Earth in a solidifying drizzle. The site appeared to contain microtektites by the million.

As DePalma carefully excavated the upper layers, he began uncovering an extraordinary array of fossils, exceedingly delicate but marvellously well preserved. “There’s amazing plant material in there, all interlaced and interlocked,” he recalled. “There are logjams of wood, fish pressed against cypress-tree root bundles, tree trunks smeared with amber.” Most fossils end up being squashed flat by the pressure of the overlying stone, but here everything was three-dimensional, including the fish, having been encased in sediment all at once, which acted as a support. “You see skin, you see dorsal fins literally sticking straight up in the sediments, species new to science,” he said. As he dug, the momentousness of what he had come across slowly dawned on him. If the site was what he hoped, he had made the most important paleontological discovery of the new century.

In a century and a half of assiduous searching, almost no dinosaur remains have been found in the layers three metres, or about nine feet, below the KT boundary, a depth representing many thousands of years.

Photograph by Richard Barnes for The New Yorker

DePalma grew up in Boca Raton, Florida, and as a child he was fascinated by bones and the stories they contained. His father, Robert, Sr., practices endodontic surgery in nearby Delray Beach; his great-uncle Anthony, who died in 2005, at the age of a hundred, was a renowned orthopedic surgeon who wrote several standard textbooks on the subject. (Anthony’s son, Robert’s cousin, is the film director Brian De Palma.)

“Between the ages of three and four, I made a visual connection with the gracefulness of individual bones and how they fit together as a system,” DePalma told me. “That really struck me. I went after whatever on the dinner table had bones in it.” His family buried their dead pets in one spot and put the burial markers in another, so that he wouldn’t dig up the corpses; he found them anyway. He froze dead lizards in ice-cube trays, which his mother would discover when she had friends over for iced tea. “I was never into sports,” he said. “They tried to get me to do that so I would get along with the other kids. But I was digging up the baseball field looking for bones.”

DePalma's great-uncle Anthony, who lived in Pompano Beach, took him under his wing. "I used to visit him every other weekend and show him my latest finds," DePalma said. When he was four, someone at a museum in Texas gave him a fragment of dinosaur bone, which he took to his great-uncle. "He taught me that all those little knobs and rough patches and protrusions on a bone had names, and that the bone also had a name," DePalma said. "I was captivated." At six or seven, on trips to Central Florida with his family, he started finding his own fossilized bones from mammals dating back to the Ice Age. He found his first dinosaur bone when he was nine, in Colorado.

In high school, during the summer and on weekends, DePalma collected fossils, made dinosaur models, and mounted skeletons for the Graves Museum of Archaeology and Natural History, in Dania Beach. He loaned the museum his childhood fossil collection for display, but in 2004 the museum went bankrupt and many of the specimens were carted off to a community college. DePalma had no paperwork to prove his ownership, and a court refused to return his fossils, which numbered in the hundreds. They were mostly locked away in storage, unavailable for public display and enjoyment.

Dismayed by what he called the "wasteful mismanagement" of his collection, DePalma adopted some unusual collecting practices. Typically, paleontologists cede the curation and the care of their specimens to the institutions that hold them. But DePalma insists on contractual clauses that give him oversight of the management of his specimens. He never digs on public land, because of what he considers excessive government red tape. But, without federal support for his work, he must cover almost all the costs himself. His out-of-pocket expenses for working the Hell Creek site amount to tens of thousands of dollars. He helps defray the expenses by mounting fossils, doing reconstructions, and casting and selling replicas for museums, private collectors, and other clients. At times, his parents have chipped in. "I squeak by," he said. "If it's a tossup between getting more PaleoBond"—an expensive liquid glue used to hold fossils together—"or changing the air-conditioning filter, I'm getting the PaleoBond." He is single, and shares a three-bedroom apartment with casts of various dinosaurs, including one of a *Nanotyrannus*. "It's hard to have a life outside of my work," he said.

DePalma's control of his research collection is controversial. Fossils are a big business; wealthy collectors pay hundreds of thousands of dollars, even millions, for a rare

specimen. (In 1997, a *T. rex* nicknamed Sue was sold at a Sotheby's auction, to the Field Museum of Natural History, in Chicago, for more than \$8.3 million.) The American market is awash in fossils illegally smuggled out of China and Mongolia. But in the U.S. fossil collecting on private property is legal, as is the buying, selling, and exporting of fossils. Many scientists view this trade as a threat to paleontology and argue that important fossils belong in museums. "I'm not allowed to have a private collection of anything I'm studying," one prominent curator told me. DePalma insists that he maintains "the best of both worlds" for his fossils. He has deposited portions of his collection at several nonprofit institutions, including the University of Kansas, the Palm Beach Museum of Natural History, and Florida Atlantic University; some specimens are temporarily housed in various analytical labs that are conducting tests on them—all overseen by him.

In 2013, DePalma briefly made news with a paper he published in the *Proceedings of the National Academy of Sciences*. Four years earlier, in Hell Creek, he and a field assistant, Robert Feeney, found an odd, lumpy growth of fossilized bone that turned out to be two fused vertebrae from the tail of a hadrosaur, a duck-billed dinosaur from the Cretaceous period. DePalma thought that the bone might have grown around a foreign object and encased it. He took it to Lawrence Memorial Hospital, in Kansas, where a CT technician scanned it for free in the middle of the night, when the machine was idle. Inside the nodule was a broken tyrannosaur tooth; the hadrosaur had been bitten by a tyrannosaur and escaped.

The discovery helped refute an old hypothesis, revived by the formidable paleontologist Jack Horner, that *T. rex* was solely a scavenger. Horner argued that *T. rex* was too slow and lumbering, its arms too puny and its eyesight too poor, to prey on other creatures. When DePalma's find was picked up by the national media, Horner dismissed it as "speculation" and merely "one data point." He suggested an alternative scenario: the *T. rex* might have accidentally bitten the tail of a sleeping hadrosaur, thinking that it was dead, and then "backed away" when it realized its mistake. "I thought that was absolutely preposterous," DePalma told me. At the time, he told the *Los Angeles Times*, "A scavenger doesn't come across a food source and realize all of a sudden that it's alive." Horner eventually conceded that *T. rex* may have hunted live prey. But, when I asked Horner about DePalma recently, he said at first that he didn't remember him: "In the community, we don't get to know students very well."

Without his Ph.D., DePalma remains mostly invisible, awaiting the stamp of approval that signals the beginning of a serious research career. Several paleontologists I talked to had not heard of him. Another, who asked not to be named, said, “Finding that kind of fossil was pretty cool, but not life-changing. People sometimes think I’m dumb because I often say I don’t have the answers—we weren’t there when a fossil was formed. There are other people out there who say they do know, and he’s one of those people. I think he can overinterpret.”

After receiving DePalma’s e-mail, I made arrangements to visit the Hell Creek site; three weeks later I was in Bowman. DePalma pulled up to my hotel in a Toyota 4Runner, its stereo blasting the theme to “Raiders of the Lost Ark.” He wore a coarse cotton work shirt, cargo pants with canvas suspenders, and a suède cowboy hat with the left brim snapped up. His face was tanned from long days in the sun and he had a five-day-old beard.

I got in, and we drove for an hour or so, turning through a ranch gate and following a maze of bone-rattling roads that eventually petered out in a grassy basin. The scattered badlands of Hell Creek form an otherworldly landscape. This is far-flung ranching and farming country; prairies and sunflower fields stretch to the horizon, domed by the great blue skies of the American West. Roads connect small towns—truck stop, church, motel, houses and trailers—and lonely expanses roll by in between. Here and there in the countryside, abandoned farmhouses lean into the ground. Over millions of years, the Hell Creek layer has been heavily eroded, leaving only remnants, which jut from the prairie like so many rotten teeth. These lifeless buttes and pinnacles are striped in beige, chocolate, yellow, maroon, russet, gray, and white. Fossils, worked loose by wind and rain, spill down the sides.

When we arrived, DePalma’s site lay open in front of us: a desolate hump of gray, cracked earth, about the size of two soccer fields. It looked as if a piece of the moon had dropped there. One side of the deposit was cut through by a sandy wash, or dry streambed; the other ended in a low escarpment. The dig was a three-foot-deep rectangular hole, sixty feet long by forty feet wide. A couple of two-by-fours, along with various digging tools and some metal pipe for taking core samples, leaned against the far side of the hole. As we strolled around the site, I noticed on DePalma’s belt a long

fixed-blade knife and a sheathed bayonet—a Second World War relic that his uncle gave him when he was twelve, he said.

He recalled the moment of discovery. The first fossil he removed, earlier that summer, was a five-foot-long freshwater paddlefish. Paddlefish still live today; they have a long bony snout, with which they probe murky water in search of food. When DePalma took out the fossil, he found underneath it a tooth from a mosasaur, a giant carnivorous marine reptile. He wondered how a freshwater fish and a marine reptile could have ended up in the same place, on a riverbank at least several miles inland from the nearest sea. (At the time, a shallow body of water, called the Western Interior Seaway, ran from the proto-Gulf of Mexico up through part of North America.) The next day, he found a two-foot-wide tail from another marine fish; it looked as if it had been violently ripped from the fish's body. "If the fish is dead for any length of time, those tails decay and fall apart," DePalma said. But this one was perfectly intact, "so I knew that it was transported at the time of death or around then." Like the mosasaur tooth, it had somehow ended up miles inland from the sea of its origin. "When I found that, I thought, There's no way, this can't be right," DePalma said. The discoveries hinted at an extraordinary conclusion that he wasn't quite ready to accept. "I was ninety-eight per cent convinced at that point," he said.

The following day, DePalma noticed a small disturbance preserved in the sediment. About three inches in diameter, it appeared to be a crater formed by an object that had fallen from the sky and plunked down in mud. Similar formations, caused by hailstones hitting a muddy surface, had been found before in the fossil record. As DePalma shaved back the layers to make a cross-section of the crater, he found the thing itself—not a hailstone but a small white sphere—at the bottom of the crater. It was a tektite, about three millimetres in diameter—the fallout from an ancient asteroid impact. As he continued excavating, he found another crater with a tektite at the bottom, and another, and another. Glass turns to clay over millions of years, and these tektites were now clay, but some still had glassy cores. The microtektites he had found earlier might have been carried there by water, but these had been trapped where they fell—on what, DePalma believed, must have been the very day of the disaster.

"When I saw that, I knew this wasn't just any flood deposit," DePalma said. "We weren't just near the KT boundary—this whole site *is* the KT boundary!" From

surveying and mapping the layers, DePalma hypothesized that a massive inland surge of water flooded a river valley and filled the low-lying area where we now stood, perhaps as a result of the KT-impact tsunami, which had roared across the proto-Gulf and up the Western Interior Seaway. As the water slowed and became slack, it deposited everything that had been caught up in its travels—the heaviest material first, up to whatever was floating on the surface. All of it was quickly entombed and preserved in the muck: dying and dead creatures, both marine and freshwater; plants, seeds, tree trunks, roots, cones, pine needles, flowers, and pollen; shells, bones, teeth, and eggs; tektites, shocked minerals, tiny diamonds, iridium-laden dust, ash, charcoal, and amber-smear wood. As the sediments settled, blobs of glass rained into the mud, the largest first, then finer and finer bits, until grains sifted down like snow.

“We have the whole KT event preserved in these sediments,” DePalma said. “With this deposit, we can chart what happened the day the Cretaceous died.” No paleontological site remotely like it had ever been found, and, if DePalma’s hypothesis proves correct, the scientific value of the site will be immense. When Walter Alvarez visited the dig last summer, he was astounded. “It is truly a magnificent site,” he wrote to me, adding that it’s “surely one of the best sites ever found for telling just what happened on the day of the impact.”

When DePalma finished showing me the dig, he introduced me to a field assistant, Rudy Pascucci, the director of the Palm Beach Museum. Pascucci, a muscular man in his fifties, was sunburned and unshaven, and wore a sleeveless T-shirt, snakeproof camouflage boots, and a dusty Tilley hat. The two men gathered their tools, got down on the floor of the hole, and began probing the three-foot-high walls of the deposit.

For rough digging, DePalma likes to use his bayonet and a handheld Marsh pick, popularized by the nineteenth-century Yale paleontologist Othniel C. Marsh, who pioneered dinosaur-hunting in the American West and discovered eighty new species. The pick was given to him by David Burnham, his thesis adviser at Kansas, when he completed his master’s degree. For fine work, DePalma uses X-Acto knives and brushes—the typical tools of a paleontologist—as well as dental instruments given to him by his father.

The deposit consisted of dozens of thin layers of mud and sand. Lower down, it graded into a more turbulent band of sand and gravel, which contained the heavier fish fossils, bones, and bigger tektites. Below that layer was a hard surface of sandstone, the original Cretaceous bedrock of the site, much of which had been scoured smooth by the flood.

Paleontology is maddening work, its progress typically measured in millimetres. As I watched, DePalma and Pascucci lay on their stomachs under the beating sun, their eyes inches from the dirt wall, and picked away. DePalma poked the tip of an X-Acto into the thin laminations of sediment and loosened one dime-size flake at a time; he'd examine it closely, and, if he saw nothing, flick it away. When the chips accumulated, he gathered them into small piles with a paintbrush; when those piles accumulated, Pascucci swept them into larger piles with a broom and then shovelled them into a heap at the far end of the dig.

Occasionally, DePalma came across small plant fossils—flower petals, leaves, seeds, pine needles, and bits of bark. Many of these were mere impressions in the mud, which would crack and peel as soon as they were exposed to the air. He quickly squirted them with PaleoBond, which soaked into the fossils and held them together. Or, using another technique, he mixed a batch of plaster and poured it on the specimen before it fell apart. This would preserve, in plaster, a reverse image of the fossil; the original was too short-lived to be saved.

When the mosquitoes got bad, DePalma took out a briar pipe and packed it with Royal Cherry Cavendish tobacco. He put a lighter to it and vigorously puffed, wreathing himself in sickly-sweet smoke, then went back to work. "I'm like a shopaholic in a shoe store," he said. "I want everything!"

He showed me the impression of a round object about two inches wide. "This is either a flower or an echinoderm," he said, referring to a group of marine life-forms that includes sea urchins and starfish. "I'll figure it out in the lab." He swiftly entombed it in PaleoBond and plaster. Next, he found a perfect leaf, and near that a seed from a pinecone. "Cretaceous mulch," he said, dismissively; he already had many similar examples. He found three more small craters with tektites in them, which he sectioned and photographed. Then his X-Acto blade turned up a tiny brown bone—a jaw, less than a quarter inch in length. He held it up between his fingers and peered at it with a lens.

“A mammal,” he said. “This one was already dead when it was buried.” Weeks later, in the lab, he identified the jaw as probably belonging to a mammal distantly related to primates—including us.

In one fell swoop, DePalma may have filled in the gap in the fossil record.

Photograph by Richard Barnes for The New Yorker

Half an hour later, DePalma discovered a large feather. “Every day is Christmas out here,” he said. He exposed the feather with precise movements. It was a crisp impression in the layer of mud, perhaps thirteen inches long. “This is my ninth feather,” he said. “The first fossil feathers ever found at Hell Creek. I’m convinced these are dinosaur feathers. I don’t know for sure. But these are primitive feathers, and most are a foot long. There are zero birds that big from Hell Creek with feathers this primitive. It’s more parsimonious to suggest it was a known dinosaur, most likely a theropod, possibly a raptor.” He kept digging. “Maybe we’ll find the raptor that these feathers came from, but I doubt it. These feathers could have floated from a long way off.”

His X-Acto knife unearthed the edge of a fossilized fin. Another paddlefish came to light; it later proved to be nearly six feet long. DePalma probed the sediment around it, to gauge its position and how best to extract it. As more of it was exposed, we could clearly see that the fish’s two-foot-long snout had broken when it was forced—probably by the flood’s surge—against the branches of a submerged araucaria tree. He noted that every fish he’d found in the site had died with its mouth open, which may indicate that the fish had been gasping as they suffocated in the sediment-laden water.

“Most died in a vertical position in the sediment, didn’t even tip over on their sides,” he said. “And they weren’t scavenged, because whatever would have dug them up afterward was probably gone.” He chipped away around the paddlefish, exposing a fin bone, then a half-dollar-size patch of fossilized skin with the scales perfectly visible. He treated these by saturating them with his own special blend of hardener. Because of the extreme fragility of the fossils, he would take them back to his lab, in Florida, totally encased in sediment, or “matrix.” In the lab, he would free each fossil under a magnifying glass, in precisely controlled conditions, away from the damaging effects of sun, wind, and aridity.

As DePalma worked around the paddlefish, more of the araucaria branch came to light, including its short, spiky needles. “This tree was alive when it was buried,” he said. Then he noticed a golden blob of amber stuck to the branch. Amber is preserved tree resin and often contains traces of whatever was in the air at the time, trapping the atmospheric chemistry and even, sometimes, insects and small reptiles. “This is Cretaceous flypaper,” he said. “I can’t wait to get this back to the lab.”

An hour later, he had chiselled all the way around the fish, leaving it encased in matrix, supported by a four-inch-tall pedestal of rock. “I’m pretty sure this is a species new to science,” he said. Because the soft tissue had also fossilized, he said, even the animal’s stomach contents might still be present.

He straightened up. “Time to plaster,” he said. He took off his shirt and began mixing a five-gallon bucket of plaster with his hands, while Pascucci tore strips of burlap. DePalma took a two-by-four and sawed off two foot-long pieces and placed them like splints on either side of the sediment-encased fossil. One by one, he dipped the burlap strips in the plaster and draped them across the top and the sides of the specimen. He added rope handles and plastered them in. An hour later, when the plaster had cured, he chiselled through the rock pedestal beneath the fossil and flipped the specimen over, leaving the underside exposed. Back in the lab, he would go through this surface to access the fossil, with the plaster jacket acting as a cradle below. Using the rope handles, DePalma and Pascucci lugged the specimen, which weighed perhaps two hundred pounds, to the truck and loaded it into the back. Later, DePalma would store it behind a friend’s ranch house, where all his jacketed fossils from the season were laid out in rows, covered with tarps.

DePalma resumed digging. Gusts of wind stirred up clouds of dust, and rain fell; when the weather cleared, the late-afternoon sun spilled across the prairie. DePalma was lost in another day, in another time. “Here’s a piece of wood with bark-beetle traces,” he said. Plant fossils from the first several million years after the impact show almost no signs of such damage; the insects were mostly gone. The asteroid had likely struck in the fall, DePalma speculated. He had reached this conclusion by comparing the juvenile paddlefish and sturgeon he’d found with the species’ known growth rates and hatching seasons; he’d also found the seeds of conifers, figs, and certain flowers. “When we analyze the pollen and diatomaceous particles, that will narrow it down,” he said.

A core sample from DePalma's site. The site may hold a precise geological transcript of the asteroid strike that almost wiped out life on the planet.

Photograph by Richard Barnes for The New Yorker

"It solves the question of whether dinosaurs went extinct at exactly that level or whether they declined before," the paleontologist Jan Smit said. "And this is the first time we see direct victims."

Photograph by Richard Barnes for The New Yorker

In the week that followed, fresh riches emerged: more feathers, leaves, seeds, and amber, along with several other fish, three to five feet long, and a dozen more craters with tektites. I have visited many paleontological sites, but I had never seen so many specimens found so quickly. Most digs are boring; days or weeks may pass with little found. DePalma seemed to make a noteworthy discovery about every half hour.

When DePalma first visited the site, he noted, partially embedded on the surface, the hip bone of a dinosaur in the ceratopsian family, of which triceratops is the best-known member. A commercial collector had tried to remove it years earlier; it had been abandoned in place and was crumbling from years of exposure. DePalma initially dismissed it as "trash" and decried the irresponsibility of the collector. Later, though, he wondered how the bone, which was heavy, had arrived there, very close to the high-water mark of the flood. It must have floated, he said, and to have done so it must have been encased in desiccated tissue—suggesting that at least one dinosaur species was alive at the time of the impact. He later found a suitcase-size piece of fossilized skin from a ceratopsian attached to the hip bone.

At one point, DePalma set off to photograph the layers of the deposit which had been cut through and exposed by the sandy wash. He scraped smooth a vertical section and misted it with water from a spray bottle to bring out the color. The bottom layer was jumbled; the first rush of water had ripped up layers of mud, gravel, and rocks and tumbled them about with pieces of burned (and burning) wood.

Then DePalma came to a faint jug-shaped outline in the wall of the wash. He examined it closely. It started as a tunnel at the top of the KT layer, went down, and then widened into a round cavity, filled with soil of a different color, which stopped at the hard sandstone of the undisturbed bedrock layer below. It looked as though a small animal had dug through the mud to create a hideout. "Is that a burrow?" I asked.

DePalma scraped the area smooth with his bayonet, then sprayed it. “You’re darn right it is,” he said. “And this isn’t the burrow of a small dinosaur. It’s a mammal burrow.” (Burrows have characteristic shapes, depending on the species that inhabit them.) He peered at it, his eyes inches from the rock, probing it with the tip of the bayonet. “Gosh, I think it’s still in there!”

He planned to remove the entire burrow intact, in a block, and run it through a CT scanner back home, to see what it contained. “Any Cretaceous mammal burrow is incredibly rare,” he said. “But this one is impossible—it’s dug right through the KT boundary.” Perhaps, he said, the mammal survived the impact and the flood, burrowed into the mud to escape the freezing darkness, then died. “It may have been born in the Cretaceous and died in the Paleocene,” he said. “And to think—sixty-six million years later, a stinky monkey is digging it up, trying to figure out what happened.” He added, “If it’s a new species, I’ll name it after you.”

When I left Hell Creek, DePalma pressed me on the need for secrecy: I was to tell no one, not even close friends, about what he’d found. The history of paleontology is full of tales of bribery, backstabbing, and double-dealing. In the nineteenth century, - Othniel C. Marsh and Edward Drinker Cope, the nation’s two leading paleontologists, engaged in a bitter competition to collect dinosaur fossils in the American West. They raided each other’s quarries, bribed each other’s crews, and vilified each other in print and at scientific meetings. In 1890, the New York *Herald* began a series of sensational articles about the controversy with the headline “SCIENTISTS WAGE BITTER WARFARE.” The rivalry has since become known as the Bone Wars. The days of skulduggery in paleontology have not passed; DePalma was deeply concerned that the site would be expropriated by a major museum.

DePalma knew that a screwup with this site would probably end his career, and that his status in the field was so uncertain that he needed to fortify the find against potential criticism. He had already experienced harsh judgment when, in 2015, he published a paper on a new species of dinosaur called a *Dakotaraptor*, and mistakenly inserted a fossil turtle bone in the reconstruction. Although rebuilding a skeleton from thousands of bone fragments that have commingled with those of other species is not easy, DePalma was mortified by the attacks. “I never want to go through that again,” he told me.

For five years, DePalma continued excavations at the site. He quietly shared his findings with a half-dozen luminaries in the field of KT studies, including Walter Alvarez, and enlisted their help. During the winter months, when not in the field, DePalma prepared and analyzed his specimens, a few at a time, in a colleague's lab at Florida Atlantic University, in Boca Raton. The lab was a windowless, wedgelike room in the geology building, lined with bubbling aquarium tanks and shelves heaped with books, scientific journals, pieces of coral, mastodon teeth, seashells, and a stack of .50--calibre machine-gun rounds, dating from the Second World War, that the lab's owner had recovered from the bottom of the Atlantic Ocean. DePalma had carved out a space for himself in a corner, just large enough for him to work on one or two jacketed fossils at a time.

When I first visited the lab, in April, 2014, a block of stone three feet long by eighteen inches wide lay on a table under bright lights and a large magnifying lens. The block, DePalma said, contained a sturgeon and a paddlefish, along with dozens of smaller fossils and a single small, perfect crater with a tektite in it. The lower parts of the block consisted of debris, fragments of bone, and loose tektites that had been dislodged and caught up in the turbulence. The block told the story of the impact in microcosm. "It was a very bad day," DePalma said. "Look at these two fish." He showed me where the sturgeon's scutes—the sharp, bony plates on its back—had been forced into the body of the paddlefish. One fish was impaled on the other. The mouth of the paddlefish was agape, and jammed into its gill rakers were microtektites—sucked in by the fish as it tried to breathe. DePalma said, "This fish was likely alive for some time after being caught in the wave, long enough to gasp frenzied mouthfuls of water in a vain attempt to survive."

Gradually, DePalma was piecing together a potential picture of the disaster. By the time the site flooded, the surrounding forest was already on fire, given the abundance of charcoal, charred wood, and amber he'd found at the site. The water arrived not as a curling wave but as a powerful, roiling rise, packed with disoriented fish and plant and animal debris, which, DePalma hypothesized, were laid down as the water slowed and receded.

In the lab, DePalma showed me magnified cross-sections of the sediment. Most of its layers were horizontal, but a few formed curlicues or flamelike patterns called truncated

flame structures, which were caused by a combination of weight from above and mini-surges in the incoming water. DePalma found five sets of these patterns. He turned back to the block on his table and held a magnifying lens up to the tektite. Parallel, streaming lines were visible on its surface—Schlieren lines, formed by two types of molten glass swirling together as the blobs arced through the atmosphere. Peering through the lens, DePalma picked away at the block with a dental probe. He soon exposed a section of pink, pearlescent shell, which had been pushed up against the sturgeon. “Ammonite,” he said. Ammonites were marine mollusks that somewhat resemble the present-day nautilus, although they were more closely related to squid and octopi. As DePalma uncovered more of the shell, I watched its vibrant color fade. “Live ammonite, ripped apart by the tsunami—they don’t travel well,” he said. “Genus *Sphenodiscus*, I would think.” The shell, which hadn’t previously been documented in the Hell Creek Formation, was another marine victim tossed inland.

He stood up. “Now I’m going to show you something special,” he said, opening a wooden crate and removing an object that was covered in aluminum foil. He unwrapped a sixteen-inch fossil feather, and held it in his palms like a piece of Lalique glass. “When I found the first feather, I had about twenty seconds of disbelief,” he said. DePalma had studied under Larry Martin, a world authority on the Cretaceous predecessors of birds, and had been “exposed to a lot of fossil feathers. When I encountered this damn thing, I immediately understood the importance of it. And now look at this.”

From the lab table, he grabbed a fossil forearm belonging to *Dakotaraptor*, the dinosaur species he’d discovered in Hell Creek. He pointed to a series of regular bumps on the bone. “These are probably quill knobs,” he said. “This dinosaur had feathers on its forearms. Now watch.” With precision calipers, he measured the diameter of the quill knobs, then the diameter of the quill of the fossil feather; both were 3.5 millimetres. “This matches,” he said. “This says a feather of this size would be associated with a limb of this size.”

There was more, including a piece of a partly burned tree trunk with amber stuck to it. He showed me a photo of the amber seen through a microscope. Trapped inside were two impact particles—another landmark discovery, because the amber would have preserved their chemical composition. (All other tektites found from the impact,