

THE DAY THE EARTH DIED

By DOUGLAS PRESTON, APRIL 8, 2019

A YOUNG PALEONTOLOGIST MAY HAVE DISCOVERED
A RECORD OF THE MOST SIGNIFICANT EVENT
IN THE HISTORY OF LIFE ON EARTH.

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



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

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

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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.

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, Robert DePalma made "an incredible and unprecedented discovery."

... 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. rex*es 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."

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.

... 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.

Micro-tektites 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 micro-tektites by the million.

... 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."

... 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.

... 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 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, exposed to the elements for millions of years, have chemically changed.) He’d also found scores of beautiful examples of lonsdaleite, a hexagonal form of diamond that is associated with impacts; it forms when carbon in an asteroid is compressed so violently that it crystallizes into trillions of microscopic grains, which are blasted into the air and drift down.

Finally, he showed me a photograph of a fossil jawbone; it belonged to the mammal he’d found in the burrow. “This is the jaw of Dougie,” he said. The bone was big for a Cretaceous mammal—three inches long—and almost complete, with a tooth. After my visit to Hell Creek, DePalma had removed the animal’s burrow intact, still encased in the block of sediment, and, with the help of some women who worked as cashiers at the Travel Center, in Bowman, hoisted it into the back of his truck. He believes that the jaw belonged to a marsupial that looked like a weasel. Using the tooth, he could conduct a stable-isotope study to find out what the animal ate—“what the menu was after the disaster,” he said. The rest of the mammal remains in the burrow, to be researched later.

DePalma says that he's discovered more than a dozen new species of animals and plants, and identified the broken teeth and bones, including hatchling remains, of almost every dinosaur group known from Hell Creek.

DePalma listed some of the other discoveries he's made at the site: several flooded ant nests, with drowned ants still inside and some chambers packed with microtektites; a possible wasp burrow; another mammal burrow, with multiple tunnels and galleries; shark teeth; the thigh bone of a large sea turtle; at least three new fish species; a gigantic ginkgo leaf and a plant that was a relative of the banana; more than a dozen new species of animals and plants; and several other burrow types.

At the bottom of the deposit, in a mixture of heavy gravel and tektites, DePalma identified the broken teeth and bones, including hatchling remains, of almost every dinosaur group known from Hell Creek, as well as pterosaur remains, which had previously been found only in layers far below the KT boundary. He found, intact, an unhatched egg containing an embryo—a fossil of immense research value. The egg and the other remains suggested that dinosaurs and major reptiles were probably not staggering into extinction on that fateful day. In one fell swoop, DePalma may have solved the three-metre problem and filled in the gap in the fossil record.

By the end of the 2013 field season, DePalma was convinced that the site had been created by an impact flood, but he lacked conclusive evidence that it was the KT impact. It was possible that it resulted from another giant asteroid strike that occurred at around the same time. "Extraordinary discoveries require extraordinary evidence," he said. If his tektites shared the same geochemistry as tektites from the Chicxulub asteroid, he'd have a strong case. Deposits of Chicxulub tektites are rare; the best source, discovered in 1990, is a small outcrop in Haiti, on a cliff above a road cut. In late January, 2014, DePalma went there to gather tektites and sent them to an independent lab in Canada, along with tektites from his own site; the samples were analyzed at the same time, with the same equipment. The results indicated a near-perfect geochemical match.

In the first few years after DePalma's discoveries, only a handful of scientists knew about them. One was David Burnham, DePalma's thesis adviser at Kansas, who estimates that DePalma's site will keep specialists busy for at least half a century. "Robert's got so much stuff that's unheard of," Burnham told me. "Amber with tektites embedded in it—holy cow! The dinosaur feathers are crazy good, but the burrow makes your head reel." In paleontology, the term *Lagerstätte* refers to a rare type of fossil site with a large variety of specimens that are nearly perfectly preserved, a sort of fossilized ecosystem. "It will be a famous site," Burnham said. "It will be in the textbooks. It is the *Lagerstätte* of the KT extinction."

Jan Smit, a paleontologist at Vrije University, in Amsterdam, and a world authority on the KT impact, has been helping DePalma analyze his results, and, like Burnham and Walter Alvarez, he is a co-author of a scientific paper that DePalma is publishing about the site. (There are eight other co-authors.) "This is really a major discovery," Smit said. "It solves the question of whether dinosaurs went extinct at exactly that level or whether they declined before. And this is the first time we see direct victims." I asked if the results would be controversial. "When I saw his data with the paddlefish, sturgeon, and ammonite, I think he's right on the spot," Smit said. "I am very sure he has a pot of gold."

In September of 2016, DePalma gave a brief talk about the discovery at the annual meeting of the Geological Society of America, in Colorado. He mentioned only that he had found a deposit from a KT flood that had yielded glass droplets, shocked minerals, and fossils. He had christened the site Tanis, after the ancient city in Egypt, which was featured in the 1981 film "Raiders of the Lost Ark" as the resting place of the Ark of the Covenant. In the real Tanis, archeologists found an inscription in three writing systems, which, like the Rosetta stone, was crucial in translating ancient Egyptian. DePalma hopes that his Tanis site will help decipher what happened on the first day after the impact.

... DePalma realized that his theory of what had happened at Tanis had a fundamental problem. The KT tsunami, even moving at more than a hundred miles an hour, would have taken many hours to travel the two thousand miles to the site.

The rainfall of glass blobs, however, would have hit the area and stopped within about an hour after the impact. And yet the tektites fell into an active flood. The timing was all wrong.

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This was not a paleontological question; it was a problem of geophysics and sedimentology. Smit was a sedimentologist, and another researcher whom DePalma shared his data with, Mark Richards, now of the University of Washington, was a geophysicist. At dinner one evening in Nagpur, India, where they were attending a conference, Smit and Richards talked about the problem, looked up a few papers, and later jotted down some rough calculations. It was immediately apparent to them that the KT tsunami would have arrived too late to capture the falling tektites; the wave would also have been too diminished by its long journey to account for the thirty-five-foot rise of water at Tanis. One of them proposed that the wave might have been created by a curious phenomenon known as a seiche. In large earthquakes, the shaking of the ground sometimes causes water in ponds, swimming pools, and bathtubs to slosh back and forth. Richards recalled that the 2011 Japanese earthquake produced bizarre, five-foot seiche waves in an absolutely calm Norwegian fjord thirty minutes after the quake, in a place unreachable by the tsunami.

Richards had previously estimated that the worldwide earthquake generated by the KT impact could have been a thousand times stronger than the biggest earthquake ever experienced in human history. Using that gauge, he calculated that potent seismic waves would have arrived at Tanis six minutes, ten minutes, and thirteen minutes after the impact. (Different types of seismic waves travel at different speeds.) The brutal shaking would have been enough to trigger a large seiche, and the first blobs of glass would have started to rain down seconds or minutes afterward. They would have continued to fall as the seiche waves rolled in and out, depositing layer upon layer of sediment and each time -sealing the tektites in place. The Tanis site, in short, did not span the first day of the impact: it probably recorded the first hour or so. This fact, if true, renders the site even more fabulous than previously thought. It is almost beyond credibility that a precise geological transcript of the most

important sixty minutes of Earth's history could still exist millions of years later—a sort of high-speed, high-resolution video of the event recorded in fine layers of stone. DePalma said, **B** “It’s like finding the Holy Grail clutched in the bony fingers of Jimmy Hoffa, sitting on top of the Lost Ark.” If Tanis had been closer to or farther from the impact point, this beautiful coincidence of timing could not have happened. “There’s nothing in the world that’s ever been seen like this,” Richards told me.

One day sixty-six million years ago, life on Earth almost came to a shattering end. The world that emerged after the impact was a much simpler place. When sunlight finally broke through the haze, it illuminated a hellish landscape. The oceans were empty. The land was covered with drifting ash. The forests were charred stumps. The cold gave way to extreme heat as a greenhouse effect kicked in. Life mostly consisted of mats of algae and growths of fungus: for years after the impact, the Earth was covered with little other than ferns. Furtive, ratlike mammals lived in the gloomy understory.

But eventually life emerged and blossomed again, in new forms. The KT event continues to attract the interest of scientists in no small part because the ashen print it left on the planet is an existential reminder. “We wouldn’t be here talking on the phone if that meteorite hadn’t fallen,” Smit told me, with a laugh. DePalma agreed. For the first hundred million years of their existence, before the asteroid struck, mammals scurried about the feet of the dinosaurs, amounting to little. “But when the dinosaurs were gone it freed them,” DePalma said. In the next epoch, mammals underwent an explosion of adaptive radiation, evolving into a dazzling variety of forms, from tiny bats to gigantic titanotheres, from horses to whales, from fearsome creodonts to large-brained primates with hands that could grasp and minds that could see through time.

“We can trace our origins back to that event,” DePalma said. “To actually be there at this site, to see it, to be connected to that day, is a special thing. This is the last day of the Cretaceous. When you go one layer up—the very next day—that’s the Paleocene, that’s the age of mammals, that’s our age.”

Vocabulary – describe the meanings of the following words from the *context* of the article.

Do NOT Google/cut-and-paste an online definition.

1) tektite

2) KT boundary

3) iridium

4) Chicxulub

5) KT-impact tsunami

6) Schlieren lines

7) lonsdaleite

8) Lagerstätte

9) Tanis

10) seiche

- 1) SUMMARIZE the importance of the Hell Creek Formation, including the comparison of T. Rex to hyenas.

- 2) SUMMARIZE the environmental conditions in the late Cretaceous epoch.

- 3) EVALUATE how the “Deccan” theory explains the KT boundary, including the “three-metre problem”.

- 4) ANALYZE how tektites are formed.

- 5) How high did the ejecta from the asteroid impact erupt from the surface of the Earth before falling back down to the ground?

- 6) How far away did some of the ejecta likely go in the solar system? Why do astrobiologists find this fact to be very important?

- 7) What percent of the Earth’s forests was incinerated from the asteroid’s impact?

- 8) What percent of the Earth’s living organisms perished from the asteroid’s impact?

9) Using the attached map, IDENTIFY the path of the KT tsunami, including the Western Interior Seaway.

10) What meaning did DePalma EXTRAPOLATE from digging up two fossils, a mosasaur and paddlefish, one right underneath the other?

11) Why is DePalma so proud of his fossil of a surgeon's scutes found in the fossil of a paddlefish?

12) The beginning of passage A reads, "This was not a paleontological question; it was a problem of geophysics and sedimentology." What problem did the sciences of geophysics and sedimentology PREDICT for the Asteroid Hypothesis?

13) How does ANALYZING the effects of the KT tsunami answer the problem?



