PROLOGUE:

The GOLDEN AGE *of* DISCOVERY

Zhenyuanlong

A FEW HOURS BEFORE LIGHT broke on a cold November morning in 2014, I got out of a taxi and pushed my way into Beijing's central railway station. I clutched my ticket as I fought through a swarm of thousands of early-morning commuters, my nerves starting to jangle as the departure time for my train ticked ever closer. I had no idea where to go. Alone, with only a few words of Chinese in my vocabulary, all I could do was try to match the pictographic characters on my ticket to the symbols on the platforms. Tunnel vision set in, and I barreled up and down the escalators, past the newsstands and noodle joints, like a predator on the hunt. My suitcase—weighed down with cameras, a tripod, and other scientific gear—bounced along behind me, rolling over feet and smacking into shins. Angry shouts seemed to come at me from all directions. But I didn't stop.

By now sweat was pouring through my downy winter jacket, and I was gasping in the diesel haze. An engine roared to life somewhere ahead of me, and a whistle sounded. A train was about to depart. I staggered down the concrete steps leading to the tracks and, to my great relief, recognized the symbols. Finally. This was my train—the one that would be shooting northeastward to Jinzhou, a Chicago-size city in old Manchuria, a few hundred miles from the frontier with North Korea.

For the next four hours, I tried to get comfortable as we crawled past concrete factories and hazy cornfields. Occasionally I nodded off, but I couldn't steal back much sleep. I was far too excited. A mystery was waiting at the end of the journey—a fossil that a farmer stumbled upon while harvesting his crops. I had seen a few grainy photos, sent to me by my good friend and colleague Junchang Lü, one of China's most famous dinosaur hunters. We both agreed it looked important. Maybe even one

of those holy grail fossils—a new species, preserved in such an immaculate way that we can sense what it was like as a living, breathing creature tens of millions of years in the past. But we needed to see it ourselves to be sure.

When Junchang and I stepped off the train in Jinzhou, we were greeted by a band of local dignitaries, who took our bags and ushered us into two black SUVs. We were whizzed off to the city's museum, a surprisingly nondescript building on the outskirts of town. With the seriousness of a high-level political summit, we were led through the flickering neon lights of a long hallway, into a side room with a couple of desks and chairs. Balanced on a small table was a slab of rock so heavy that it seemed the legs were starting to buckle. One of the locals spoke in Chinese to Junchang, who then turned to me and gave a quick nod.

"Let's go," he said, in his curiously accented English, a combination of the Chinese cadence he grew up with and the Texas drawl that he picked up as a grad student in America.

The two of us came together and stepped toward the table. I could feel the eyes of everyone, an eerie silence hanging over the room as we approached the treasure.

Before me was one of the most beautiful fossils I had ever seen. It was a skeleton, about the size of a mule, its chocolate-brown bones standing out from the dull gray limestone surrounding it. A dinosaur for sure, its steak-knife teeth, pointy claws, and long tail leaving no doubt that it was a close cousin of *Jurassic Park*'s villainous *Velociraptor.*

But this was no ordinary dinosaur. Its bones were light and hollow, its legs long and skinny like a heron's, its slender skeleton the hallmark of an active, dynamic, fast-moving animal.

And not only were there bones, but there were feathers covering the entire body. Bushy feathers that looked like hair on the head and neck, long branching feathers on the tail, and big quill pens on the arms, lined together and layered over each other to form wings.

This dinosaur looked just like a bird.

About a year later, Junchang and I described this skeleton as a new species, which we called *Zhenyuanlong suni*. It is one of about fifteen new dinosaurs that I've identified over the past decade, as I've carved out a career in paleontology that has taken me from my roots in the American Midwest to a faculty job in Scotland, with many stops all over the world to find and study dinosaurs.

Zhenyuanlong is unlike the dinosaurs I learned about in elementary school, before I became a scientist. I was taught that dinosaurs were big, scaly, stupid brutes so ill equipped for their environment that they just lumbered around, biding their time, waiting to go extinct. Evolutionary failures. Dead ends in the history of life. Primitive beasts that came and went, long before humans came on the scene, in a primeval world that was so different from today that it may as well have been an alien planet. Dinosaurs were curiosities to see in museums, or movie monsters that haunted our nightmares, or objects of childhood fascination, pretty much irrelevant to us today and unworthy of any serious study.

But these stereotypes are absurdly wrong. They've been dismantled over the past few decades, as a new generation has collected dinosaur fossils at an unprecedented rate. Somewhere around the world—from the deserts of Argentina to the frozen

Zhenyuanlong.

wastelands of Alaska—a new species of dinosaur is currently being found, on average, once a week. Let that sink in: a new dinosaur every . . . single . . . week. That's about fifty new species each year—*Zhenyuanlong* among them. And it's not only new discoveries but also novel ways of studying them—emerging technologies that help paleontologists understand the biology and evolution of dinosaurs in ways that our elders would have found unimaginable. CAT scanners are being used to study dinosaur brains and senses, computer models tell us how they

moved, and high-power microscopes can even reveal what color some of them were. And so on.

It's been my great privilege to be part of this excitement—as one of many young paleontologists from across the globe, men

Junchang Lü and I studying the gorgeous fossil of *Zhenyuanlong*.

and women from many backgrounds who came of age in the era of *Jurassic Park*. There are a whole bunch of us twenty- and thirty-something researchers, working together and with our mentors from the preceding generation. With each new discovery we make, each new study, we learn a little more about dinosaurs and their evolutionary story.

That is the tale I am going to tell in this book—the epic account of where dinosaurs came from, how they rose to dominance, how some of them became colossal and others developed feathers and wings and turned into birds, and then how the rest of them disappeared, ultimately paving the way for the modern world, and for us. In doing so, I want to convey how we've pieced together this story using the fossil clues that we have, and give some sense of what it's like to be a paleontologist whose job it is to hunt for dinosaurs.

Most of all, though, I want to show that dinosaurs were not aliens, nor were they failures, and they're certainly not irrelevant. They were remarkably successful, thriving for over 150 million years and producing some of the most amazing animals that have ever lived—including birds, some ten thousand species of modern-day dinosaurs. Their home was our home—the same Earth, subject to the same whims of climate and environmental change that we have to deal with, or perhaps will deal with in the future. They evolved in concert with an ever changing world, one subject to monstrous volcanic eruptions and asteroid impacts, and one in which the continents were moving around, sea levels were constantly fluctuating, and temperatures were capriciously rising and falling. They became supremely well adapted to their environments, but in the end, most of them

went extinct when they couldn't cope with a sudden crisis. No doubt there is a lesson there for us.

More than anything, the rise and fall of the dinosaurs is an incredible story, of a time when giant beasts and other fantastic creatures made the world their own. They walked on the very ground below us, their fossils now entombed in rock—the clues that tell this story. To me, it's one of the greatest narratives in the history of our planet.

STEVE BRUSATTE
Edinburgh, Scotland
MAY 18, 2017

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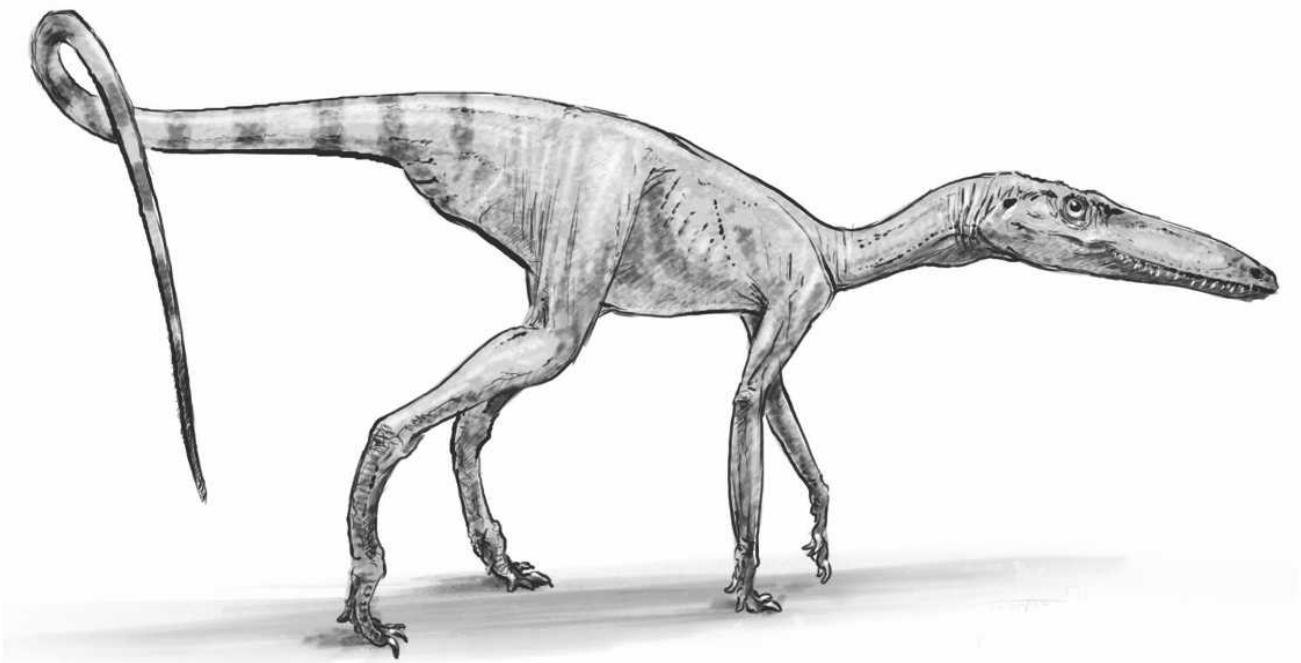
The DAWN OF *the* DINOSAURS



Prorotodactylus

"BINGO," MY FRIEND GRZEGORZ NIEDŹWIEDZKI shouted, pointing at a knife-thin separation between a slim strip of mudstone and a thicker layer of coarser rock right above it. The quarry we were exploring, near the tiny Polish village of Zachełmie, was once a source of sought-after limestone but had long been abandoned. The surrounding landscape was littered with decaying smokestacks and other remnants of central Poland's industrial past. The maps deceitfully told us we were in the Holy Cross Mountains, a sad patch of hills once grand but now nearly flattened by hundreds of millions of years of erosion. The sky was gray, the mosquitoes were biting, heat was bouncing off the quarry floor, and the only other people we saw were a couple of wayward hikers who must have made a tragically wrong turn.

"This is the extinction," Grzegorz said, a big smile creasing the unshaven stubble of many days of fieldwork. "Many footprints of big reptiles and mammal cousins below, but then they disappear. And above, we see nothing for awhile, and then dinosaurs."

We may have been peering at some rocks in an overgrown quarry, but what we were really looking at was a revolution. Rocks record history; they tell stories of deep ancient pasts long before humans walked the Earth. And the narrative in front of us, written in stone, was a shocker. That switch in the rocks, detectable perhaps only to the overtrained eyes of a scientist, documents one of the most dramatic moments in Earth history. A brief instance when the world changed, a turning point that happened some 252 million years ago, before us, before woolly mammoths, before the dinosaurs, but one that still reverberates today. If things had unfolded a little differently back then, who

knows what the modern world would be like? It's like wondering what might have happened if the archduke was never shot.

IF WE'D BEEN standing in this same spot 252 million years ago, during a slice of time geologists call the Permian Period, our surroundings would have been barely recognizable. No ruined factories or other signs of people. No birds in the sky or mice scurrying at our feet, no flowery shrubs to scratch us up or mosquitoes to feed on our cuts. All of those things would evolve later. We still would have been sweating, though, because it was hot and unbearably humid, probably more insufferable than Miami in the middle of the summer. Raging rivers would've been draining the Holy Cross Mountains, which were actually proper mountains back then, with sharp snowy peaks jutting tens of thousands of feet into the clouds. The rivers wound their way through vast forests of conifer trees—early relatives of today's pines and junipers—emptying into a big basin flanking the hills, dotted with lakes that swelled in the rainy season but dried out when the monsoons ended.

These lakes were the lifeblood of the local ecosystem, watering holes that provided an oasis from the harsh heat and wind. All sorts of animals flocked to them, but they weren't animals we would know. There were slimy salamanders bigger than dogs, loitering near the water's edge and occasionally snapping at a passing fish. Stocky beasts called pareiasaurs waddled around on all fours, their knobby skin, front-heavy build, and general brutish appearance making them seem like a mad reptilian offensive lineman. Fat little things called dicynodonts rummaged around in the muck like pigs, using their sharp tusks to

pry up tasty roots. Lording over it all were the gorgonopsians, bear-size monsters who reigned at the top of the food chain, slicing into pareiasaur guts and dicynodont flesh with their saberlike canines. This cast of oddballs ruled the world right before the dinosaurs.

Then, deep inside, the Earth began to rumble. You wouldn't have been able to feel it on the surface, at least when it kicked off, right around 252 million years ago. It was happening fifty, maybe even a hundred, miles underground, in the mantle, the middle layer of the crust-mantle-core sandwich of Earth's structure. The mantle is solid rock that is so hot and under such intense pressure that, over long stretches of geological time, it can flow like extra-viscous Silly Putty. In fact, the mantle has currents just like a river. These currents are what drive the conveyor-belt system of plate tectonics, the forces that break the thin outer crust into plates that move relative to each other over time. We wouldn't have mountains or oceans or a habitable surface without the mantle currents. However, every once in a while, one of the currents goes rogue. Hot plumes of liquid rock break free and start snaking their way upward to the surface, eventually bursting out through volcanoes. These are called hot spots. They're rare, but Yellowstone is an example of an active one today. The constant supply of heat from the deep Earth is what powers Old Faithful and the other geysers.

This same thing was happening at the end of the Permian Period, but on a continent-wide scale. A massive hot spot began to form under Siberia. The streams of liquid rock rushed through the mantle into the crust and flooded out from volcanoes. These weren't ordinary volcanoes like the ones we're most used to, the cone-shaped mounds that sit dormant for decades and then

occasionally explode with a bunch of ash and lava, like Mount Saint Helens or Pinatubo. They wouldn't have erupted with the vigor of those vinegar-and-baking-soda contraptions so many of us made as science fair experiments. No, these volcanoes were nothing more than big cracks in the ground, often miles long, that continuously belched out lava, year after year, decade after decade, century after century. The eruptions at the end of the Permian lasted for a few hundred thousand years, perhaps even a few million. There were a few bigger eruptive bursts and quieter periods of slower flow. All in all, they expelled enough lava to drown several million square miles of northern and central Asia. Even today, more than a quarter billion years later, the black basalt rocks that hardened out of this lava cover nearly a million square miles of Siberia, about the same land area as Western Europe.

Imagine a continent scorched with lava. It's the apocalyptic disaster of a bad B movie. Suffice it to say, all of the pareiasaurs, dicynodonts, and gorgonopsians living anywhere near the Siberian area code were finished. But it was worse than that. When volcanoes erupt, they don't expel only lava, but also heat, dust, and noxious gases. Unlike lava, these can affect the entire planet. At the end of the Permian, these were the real agents of doom, and they started a cascade of destruction that would last for millions of years and irrevocably change the world in the process.

Dust shot into the atmosphere, contaminating the high-altitude air currents and spreading around the world, blocking out the sun and preventing plants from photosynthesizing. The once lush conifer forests died out; then the pareiasaurs and dicynodonts had no plants to eat, and then the gorgonopsians had no meat. Food chains started to collapse. Some of the dust fell

back through the atmosphere and combined with water droplets to form acid rain, which exacerbated the worsening situation on the ground. As more plants died, the landscape became barren and unstable, leading to massive erosion as mudslides wiped out entire tracts of rotting forest. This is why the fine mudstones in the Zachełmie quarry, a rock type indicative of calm and peaceful environments, suddenly gave way to the coarser boulder-strewn rocks so characteristic of fast-moving currents and corrosive storms. Wildfires raged across the scarred land, making it even more difficult for plants and animals to survive.

But those were just the short-term effects, the things that happened within the days, weeks, and months after a particularly large burst of lava spilled through the Siberian fissures. The longer-term effects were even more deadly. Stifling clouds of carbon dioxide were released with the lava. As we know all too well today, carbon dioxide is a potent greenhouse gas, which absorbs radiation in the atmosphere and beams it back down to the surface, warming up the Earth. The CO_2 spewed out by the Siberian eruptions didn't raise the thermostat by just a few degrees; it caused a runaway greenhouse effect that boiled the planet. But there were other consequences as well. Although a lot of the carbon dioxide went into the atmosphere, much of it also dissolved into the ocean. This causes a chain of chemical reactions that makes the ocean water more acidic, a bad thing, particularly for those sea creatures with easily dissolvable shells. It's why we don't bathe in vinegar. This chain reaction also draws much of the oxygen out of the oceans, another serious problem for anything living in or around water.

Descriptions of the doom and gloom could go on for pages, but the point is, the end of the Permian was a very bad time to be

alive. It was the biggest episode of mass death in the history of our planet. Somewhere around 90 percent of all species disappeared. Paleontologists have a special term for an event like this, when huge numbers of plants and animals die out all around the world in a short time: a mass extinction. There have been five particu larly severe mass extinctions over the past 500 million years. The one 66 million years ago at the end of the Cretaceous period, which wiped out the dinosaurs, is surely the most famous. We'll get to that one later. As horrible as the end-Cretaceous extinction was, it had nothing on the one at the end of the Permian. That moment of time 252 million years ago, chronicled in the swift change from mudstone to pebbly rock in the Polish quarry, was the closest that life ever came to being completely obliterated.

Then things got better. They always do. Life is resilient, and some species are always able to make it through even the worst catastrophes. The volcanoes erupted for a few million years, and then they stopped as the hot spot lost steam. No longer blighted by lava, dust, and carbon dioxide, ecosystems were gradually able to stabilize. Plants began to grow again, and they diversified. They provided new food for herbivores, which provided meat for carnivores. Food webs reestablished themselves. It took at least five million years for this recovery to unfold, and when it did, things were better but now very different. The previously dominant gorgonopsians, pareiasaurs, and their kin were never to stalk the lakesides of Poland or anywhere else while the plucky survivors had the whole Earth to themselves. A largely empty world, an uncolonized frontier. The Permian had transitioned into the next interval of geological time, the Triassic, and things would never be the same. Dinosaurs were about to make their entrance.