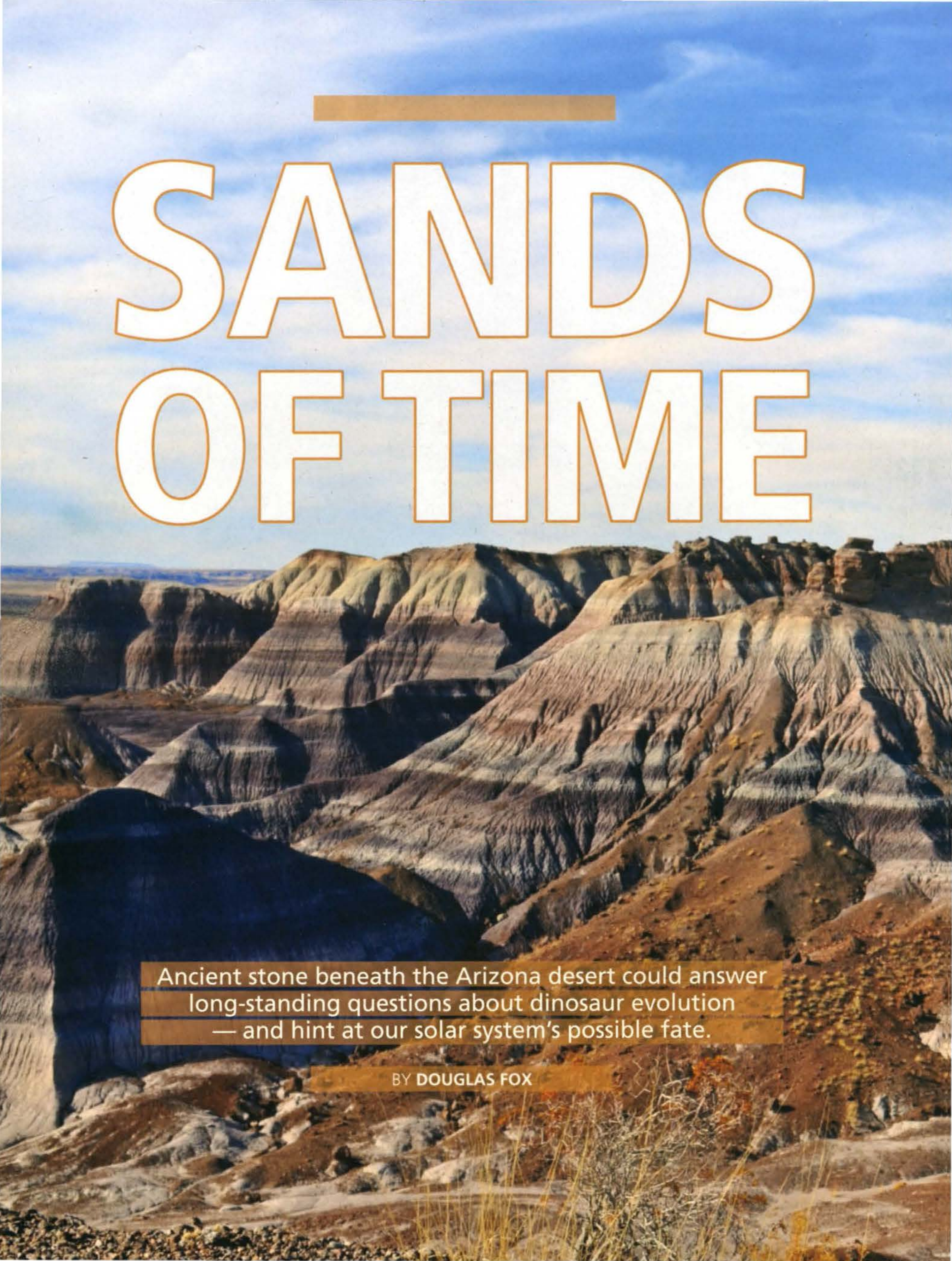
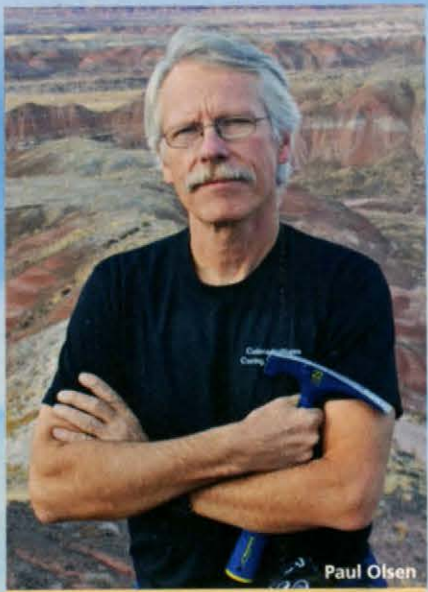
SANDS OF TIME



Ancient stone beneath the Arizona desert could answer long-standing questions about dinosaur evolution — and hint at our solar system's possible fate.

BY **DOUGLAS FOX**



A deep-bellied rumble reverberates through an expanse of tired, wrinkled badlands. A diesel truck sits atop a mesa, a metal shaft extending downward from the rear of its bed, piercing the earth like a stinger. The shaft spins 20 times per second. Hundreds of feet below, its diamond-crusted end grinds through layer after layer of sedimentary stone. The hard-hat workers running this rig often drill for gold or other valuable metals. But today they're drilling for something entirely different.

The workers idle the drill, and the roar abates. They hoist a cylinder from the hole, as long and skinny as a person's arm, and hurry it into a tent and onto a table. Hidden inside the muddy plastic cylinder is a section of core from a long-buried world. For stone, it is surprisingly fragile. The sheath protects it from swelling and crumbling.

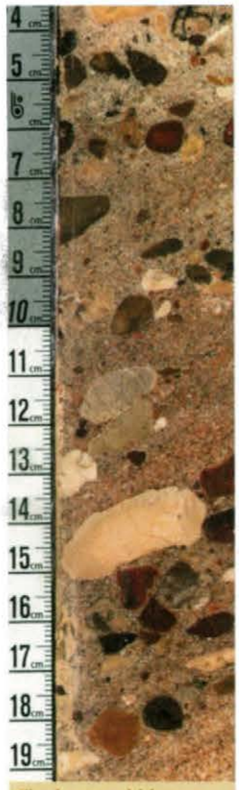
In Arizona's Painted Desert, paleontologist Paul Olsen is drilling into multihued rock layers more than 200 million years old in hopes of confirming his controversial timeline for the late Triassic period.

KEVIN KRAJICK/LAMONT-DOHERTY EARTH OBSERVATORY/COLUMBIA UNIVERSITY

Paleontologist Paul Olsen kneels for a look at the round cross-section of stone at the end of the core. It is bluish, cluttered with gray, oblong shapes.

All day and night for the past week, core sections have emerged from the drill hole every few minutes. Their blue, gray or reddish colors mirror the stone layers exposed on the surrounding badlands here in Arizona's Petrified Forest National Park. This landscape, comprising the so-called Chinle formation, coalesced from layers of mud and gravel laid down over 200 million years ago. Back then, this area was a land of tropical forests, floodplains, lakes and meandering rivers.

Olsen and his colleagues will study these cores for years to come. But even now, Olsen, with Columbia University's Lamont-Doherty Earth Observatory in Palisades, N.Y., can intuit something about how these ancient landscapes evolved. The reddish layers represent dry patches of ground where oxygen seeped into the soil and rusted the iron minerals in it. The blue-gray layers show where the drill penetrated the bed of an ancient lake or river; low oxygen levels prevented the iron minerals from rusting. Some cores even hold traces of ancient plant roots or animal burrows.



The large pebbles in this Triassic core from the Chinle formation in Arizona once tumbled down a fast-moving stream.

Inside this particular section of core, Olsen finds chicken egg-size river cobbles — evidence of a current "strong enough to move those pieces of rock," he says.

At 61 years old, Olsen is lean and rangy, with a Teddy Roosevelt mustache and wire-rim spectacles. For most of his life, he has studied the Triassic, which stretched 200 million to 250 million years ago and included the emergence of early dinosaurs. Now, working in Arizona, in one of the world's most enigmatic Triassic deposits, Olsen and his colleagues aim to reshuffle the rocky layers of history and transform our understanding of how dinosaurs came to dominate Earth.

During the Triassic, the world's continents were locked together in a single supercontinent called Pangaea, allowing animals to roam unimpeded by large bodies of water. But Olsen and others believe that for 30 million years after dinosaurs first appeared, they remained stranded, for the most part, in the geographic fringes of this world. They were confined by their own novel physiology, which differed from other reptiles and amphibians and limited where they could live. Not until after a catastrophic chain of volcanic eruptions cooled the Earth and decimated those competitors did dinosaurs become dominant worldwide. This idea is still "highly debated," Olsen admits. The Chinle coring project, he says, "hopefully will provide the linchpin" to confirm it.

The research team's coring drill, seen here at sunset, bores deep into Arizona's Painted Desert to extract ancient stone. By the end of the monthlong project, workers had drilled through 1,700 feet of rock.

A segment of core extracted from the Chinle formation. Olsen and his team are now analyzing these cores for clues about how dinosaurs evolved more than 200 million years ago during the late Triassic.

Stacked cores from the Chinle drilling project. The different colors show how the Triassic landscape changed over time due to shifts in climate.

But Olsen's interest in these rocks doesn't stop there. He's also investigating another mystery that is at once stranger, darker and more profound. Odd as it sounds, he plans to read the ancient, ephemeral motions of Mercury, Venus and Mars in those very same rocks — and test some fundamental assumptions about the cosmic clockwork that keeps our solar system's inner planets orbiting in perfect sync. If the suspicions of Olsen and a few other scientists are right, then unspeakable violence may lurk in our solar system's future — maybe even a premature end for Earth.

A MESSAGE FROM THE PAST

Olsen's journey into these questions began 45 years ago in the late 1960s, while he was a teenager growing up in Livingston, N.J., outside Newark. He and his friends spent entire days at an abandoned quarry, chiseling out reptile footprints and fish fossils. The quarry provided a window into changing Triassic climates: Layers of red sandstone, often containing footprints, represented times when the area was a muddy marsh. Interspersed in the red stone were narrow bands of black shale containing petrified fish, from a time when a deep lake covered the area. Olsen began searching beyond the quarry for petrified fish, always seeking out the black layers he knew would hold them.

Olsen looked for places where creeks had chewed away the soil, leaving the rock layers exposed. Walking along the banks, he scrutinized the red pebbles; a single shard of black among them would alert him to a shale layer somewhere upstream. The thin, black layers weren't too hard to find. They always occurred in the same curious pattern, against a background of red rock: first a single black layer, then two black layers close together, then three close together, then another three, then two. This whole sequence repeated over and over again, up and down the strata — a mysterious telegraph signal conveying some unknown message from the past. Olsen thought about it often.

He earned C's and D's in high school math and English, hindered by dyslexia and a lazy eye. But he possessed a knack for seeing patterns in the rock that seasoned geologists missed.

Olsen could predict where he would find the next batch of black strata, based on the tilt of the layers and the regular distances between them. Often it was dozens of miles away. When he turned 17, he bought a Chevy Blazer with help from his parents and followed his curiosity across Pennsylvania, Connecticut, Virginia and North Carolina. He found that these repeating layers — long thought to be local — actually extended across the region. He updated published geologic maps and sketched fossils that were new to science.

Those endeavors landed Olsen where his shabby grades never could have: at Yale, where he studied geology. Those repeating layers that captivated him as a teenager drew him into a lifelong career studying the Triassic.

The period intrigued Olsen because it was a time of great beginnings. "Everything that dominates the world now, all the major groups on land, originated in the Triassic," including frogs, salamanders, turtles, crocodiles, mammals and birds, says Olsen. And late in the Triassic, the first dinosaurs appeared.

Reconstructing those beginnings has proven difficult, though. Paleontologists sometimes build timelines from ancient ocean beds, where 100 million years of sediment layers are often stacked in one continuous sequence. But the Triassic is too old: Those pieces of oceanic crust have long since slid under the edges of continents and melted into magma. Paleontologists must instead assemble timelines from fragments, such as sediment layers from short-lived inland seas.

As a result, there is no agreed-upon timeline for the Triassic, no universal yardstick to compare the ages of Triassic fossils around the world. This means scientists can't agree about when, and in what order, various species appeared and vanished.

The red and black layers, Olsen believed, provided an opportunity to fill these gaps. In that region, called the Newark Basin, 5 miles of sediment layers spanning 32 million years had piled up in a sinking basin.

This Connecticut roadcut shows the layers of black rock in the Newark formation, which Olsen and his team used to create a Triassic timeline.

Olsen continued his modest studies of the region, bolstering his ideas before undertaking something large and expensive. By 1990, he finally had the funding to complete the mapping project he started as a teen. Rather than relying on exposed rocks, he drilled thousands of feet into the ground and extracted eight cores, from New Jersey, Pennsylvania and Connecticut comprising 26,700 feet of stacked layers. The Newark coring project confirmed the ideas that Olsen formulated as a teenager. The regularly stacked red and black layers showed up clearly in the cores: The pattern really did extend up and down the Atlantic coast. "It was breathtakingly exciting," he recalls.

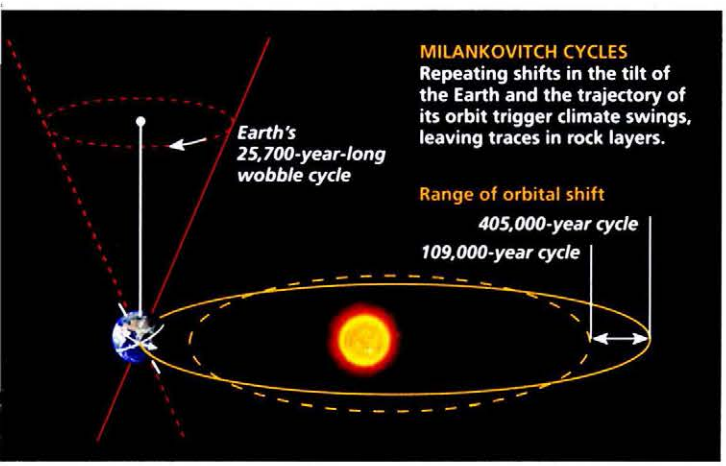
Despite this success, Olsen still needed to determine the ages of the layers; scientists can date only certain types of rocks. He could extract only two ages from the 26,700 feet of core, from a pair of volcanic rock layers near the top.

To circumvent this problem, Olsen turned to an experimental technique that would allow him to use those repeating red and black layers as markers of time. He recalled that Franklyn Van Houten, a Princeton scientist whom he met as a teenager, interpreted those dry and wet climate layers as evidence of something called Milankovitch cycles. In the 1960s, Van Houten and a few other scientists started

OPPOSITE, CLOCKWISE FROM LEFT: COLORADO PLATEAU CORING PROJECT; KEVIN KRAJICK/LAMONT-DOHERTY EARTH OBSERVATORY/COLUMBIA UNIVERSITY (2); COLORADO PLATEAU CORING PROJECT. THIS PAGE: COURTESY GILBERT N. HANSON to believe that Earth gradually wobbles in a repeating pattern, affecting the planet's trajectory around the sun. These orbital cycles, which alter the intensity of sunlight arriving in summer and winter, were thought to trigger periodic climate swings (including ice ages) and changes in precipitation.

These climate shifts, the theory went, were caused by the combined effects of three cycles: A wobble in Earth's axis repeating every 25,700 years, on average, and orbital shifts repeating every 109,000 years and every 405,000 years, respectively. Based on his studies of exposed rock faces scattered around New Jersey, Van Houten believed he saw the 25,700-year wobble cycle imprinted in the Newark layers.

With 5 miles of cores in hand, Olsen looked again at those wet and dry climate layers to see if he could use those cycles as units of time. He was amazed to see that the 25,700-year,



109,000-year and 405,000-year cycles overlaid clearly onto the relative thickness and spacing of the Newark layers, suggesting that the ancient climate swings recorded in them really were caused by Milankovitch cycles.

The idea of these climate-influencing cycles, once widely ridiculed, offered Olsen a much-needed tool. Starting with the dated lava layers at the top, he used the 405,000-year cycle — the one most clearly visible in the repeating layers — as a measuring stick to tick off a series of 405,000-year time increments down the rest of the core. This provided a way of knowing the age of any particular layer within it.

This timeline — combined with other methods, such as reading the magnetic "barcode" left in sediment by the periodic flip of Earth's magnetic poles — would provide the fine resolution of just a few thousand years that Olsen and his colleagues needed to compare the ages of fossils from around the world. Finally, they could get a clear picture of how dinosaurs first evolved and populated Earth.

Olsen and geologist Dennis Kent (also of Lamont-Doherty) published the new timeline, called the Newark astrochronology, in 1995. It contradicted some major assumptions about the Triassic world. Most paleontologists believed that any dinosaurs alive in the late Triassic would simultaneously inhabit all of Pangaea — a reasonable assumption, since the continents were melded into a single landmass stretching nearly from the North Pole to the South Pole, allowing animals to roam freely. But Newark showed something different.

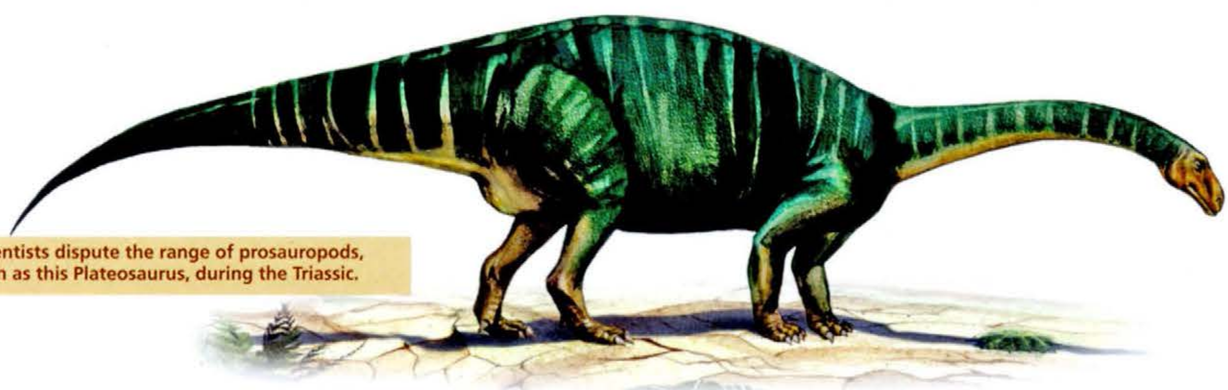
Newark layers with very few dinosaur fossils lined up in age with deposits in Europe, India, southern Africa and South America that were littered with early dinosaurs called prosauropods, which would later spawn brontosaurs and other long-necked, four-legged beasts. This suggested that for 30 million years, while early dinosaurs thrived in some parts of Pangaea, only a few small-bodied species — none of them prosauropods — managed to gain a foothold in what became North America. "There has to be something ecological going on that just doesn't let these animals establish themselves" in that area of the world, says Olsen.

DUELING TIMELINES

This emerging theory raises some startling questions about evolution. If you overlay Pangaea with the locations where his timeline says that dinosaurs did and didn't dominate in the late Triassic, a striking pattern emerges: Amphibians and crocodilian reptiles dominate the warm, equatorial regions where North America sat at the time, while dinosaurs and mammalian ancestors abound in cooler and wetter regions, north and south.

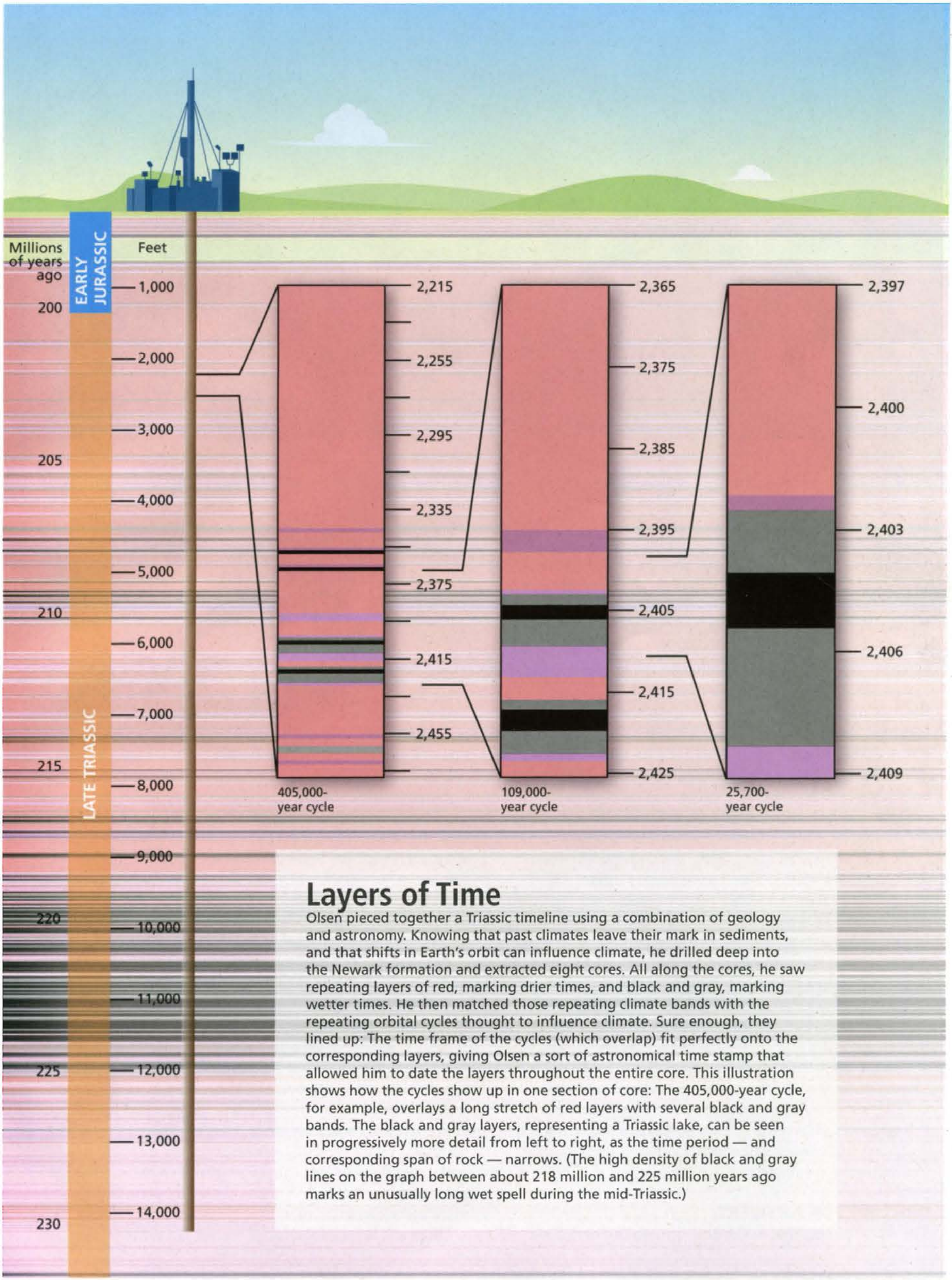
"That bears on the fundamental nature of what dinosaurs are and why they became dominant," says Olsen. Studies of skeletal anatomy and growth rates suggest dinosaurs may have been warm-blooded, allowing them to grow quickly. Randall Irmis, a paleontologist at the University of Utah who leads the Chinle drilling project, believes that for the most part, dinosaurs remained confined to that high-latitude niche for 30 million years after they first evolved; their larger size and rapid metabolism made it difficult for them to find food in the hot, seasonally dry climate of the equatorial regions.

Not until 201 million years ago did dinosaurs begin to dominate worldwide, say Olsen and Irmis — after a mass



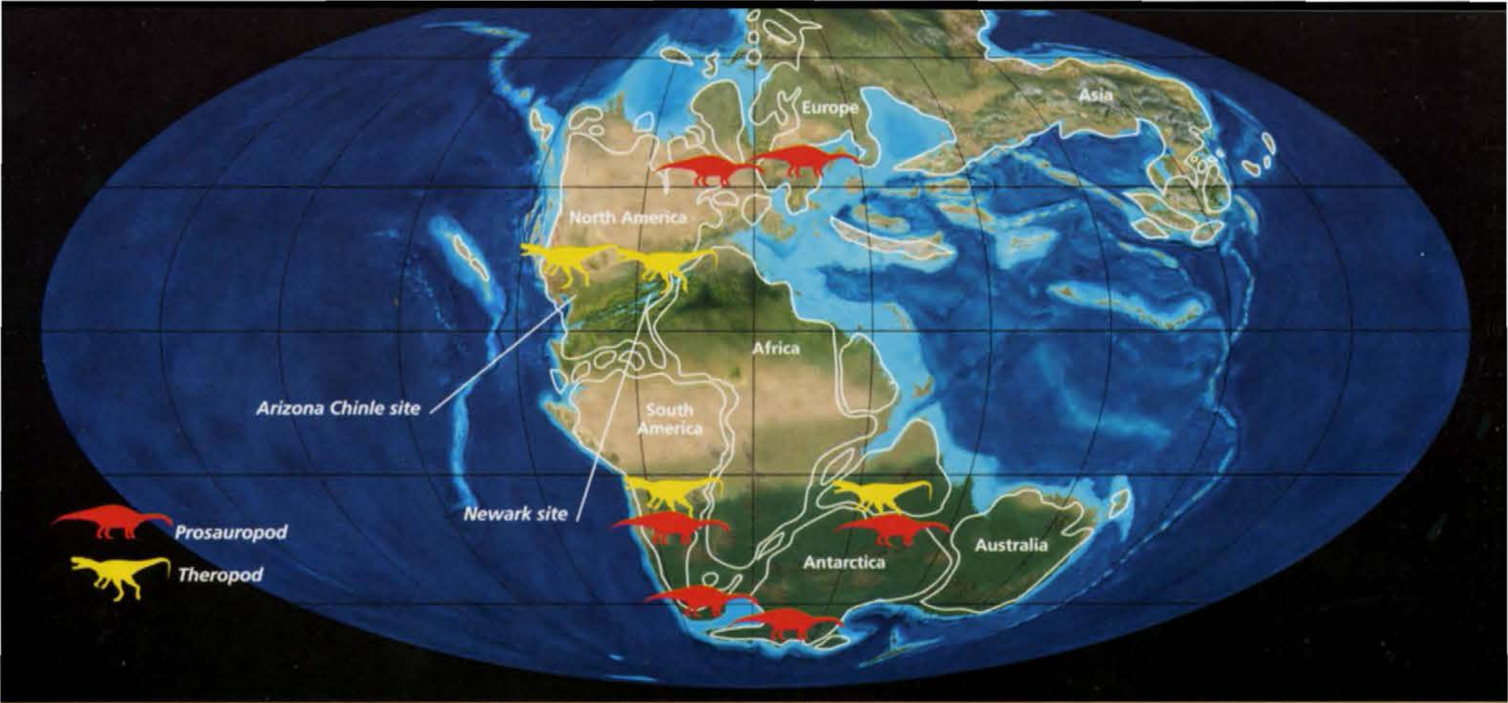
Scientists dispute the range of prosauropods, such as this Plateosaurus, during the Triassic.

PROSAUROPOD: SERGEY KRASOVSKIY/STOCKTREK IMAGES/CORBIS. ABOVE AND OPPOSITE: JAY SMITH



Layers of Time

Olsen pieced together a Triassic timeline using a combination of geology and astronomy. Knowing that past climates leave their mark in sediments, and that shifts in Earth's orbit can influence climate, he drilled deep into the Newark formation and extracted eight cores. All along the cores, he saw repeating layers of red, marking drier times, and black and gray, marking wetter times. He then matched those repeating climate bands with the repeating orbital cycles thought to influence climate. Sure enough, they lined up: The time frame of the cycles (which overlap) fit perfectly onto the corresponding layers, giving Olsen a sort of astronomical time stamp that allowed him to date the layers throughout the entire core. This illustration shows how the cycles show up in one section of core: The 405,000-year cycle, for example, overlays a long stretch of red layers with several black and gray bands. The black and gray layers, representing a Triassic lake, can be seen in progressively more detail from left to right, as the time period — and corresponding span of rock — narrows. (The high density of black and gray lines on the graph between about 218 million and 225 million years ago marks an unusually long wet spell during the mid-Triassic.)



A map of Pangaea during the late Triassic shows where evidence of prosauropod dinosaurs and theropod dinosaurs has been found. (Modern-day continents are outlined in white.) Under Olsen and other scientists' interpretation of the evidence, prosauropods remained confined to the higher, cooler latitudes for 30 million years after dinosaurs first appeared and became dominant only after volcanic eruptions wiped out many of their competitors.

extinction, caused by volcanic eruptions, wiped out many of their cold-blooded reptile and amphibian competitors. This would have been one of the greatest extinctions of all time. But Spencer Lucas, a former Yale schoolmate of Olsen's and now a renowned Triassic authority at the New Mexico Museum of Natural History, disputes its very existence. Lucas has spent 30 years assembling his own Triassic timeline using biostratigraphy. With this method, which uses specific types of fossils to determine the age of the layers that hold them, evolution itself becomes a marker of geologic time in the rocks. His fossil-based timeline shows only a series of smaller extinctions in the late Triassic.

Lucas points out plenty of weaknesses in the Newark astrochronology. Its Triassic layers contain footprints that he and his colleagues attribute to prosauropod dinosaurs (an interpretation that Olsen and others dispute). He ridicules the reliance on only two firm rock ages. And he points out that using layer thickness to measure Milankovitch cycles requires a risky assumption: that the rate of sediment accumulation, which built these layers, did not change much over 32 million years. Most damningly, he believes the cores are riddled with unseen gaps where erosion periodically obliterated sediments, potentially throwing off the timeline by millions of years.

"It's an enormous scientific house of cards," he says. "What we need to do is kick that house over and move on."

Olsen remains undeterred by Lucas' skepticism. He believes the 1,600 feet of Chinle cores extracted from Arizona's high desert will confirm what he saw in Newark and settle the argument.

DRILLING FOR ANSWERS

The day after our chat at the drill site, Olsen drives down a winding road in the Petrified Forest, munching arugula and dried red chilies. When traveling, "I really try to skip meals," he says.

Theropods, such as this Herrerasaurus, evolved into birds.

The gray and pink-striped badlands flitting past us represent one of the richest, yet hardest to understand, Triassic fossil deposits in the world. Layers in the Chinle formation, which stretches from West Texas to Nevada, are hard to trace horizontally due to faulting and tilting and because the types of rocks making up the layers change over small distances — a result of the heterogeneous landscape of forests, rivers, lakes and swamps that formed them.

Paleontologists have unearthed thousands of skeletons here. As with Newark, they include plenty of amphibians and crocodilian reptiles — even some small dinosaurs called theropods — but not a single prosauropod, say Olsen and Irmis. Lucas and his colleagues disagree. They interpret fossil footprints found in Chinle strata around the region as belonging to prosauropods. In Arizona, Lucas and his team have assembled the layers exposed across the park into a single combined sequence. They place the stack of layers between about 212 million and 225 million years old. That's in line with other fossil beds in Europe and South America that show prosauropod dinosaurs were gradually becoming larger and more common at that time.

Olsen and his collaborators, however, believe that Lucas'

TOP: RON BLAKEY/COLORADO PLATEAU GEOSYSTEMS. BOTTOM: SERGEY KRASOVSKIY/STOCKTREK IMAGES/CORBIS footprint interpretations and age estimates are wrong. He prefers an alternative Chinle timeline constructed by William Parker, a National Park Service paleontologist. Parker claims to correct a major error in Lucas' timeline — the accidental omission of nearly 200 feet of strata. When Parker adds the omitted strata back into his timeline, the overall chronology changes: The upper layers of the Chinle formation are about 5 million years younger — no more than 207 million years old.

Parker's estimate, if correct, means those Chinle layers lacking prosauropods are young enough to align with strata from high-latitude areas of Pangaea where the fossil record shows prosauropods had become plentiful. This heightens the contrast between dinosaur populations at the high and low latitudes. And it's just what Irmis and Olsen would expect, since they believe prosauropods and other large dinosaurs thrived for 30 million years at high latitudes before managing to establish in the tropics after a mass extinction 201 million years ago.

Just before dusk, I walk with Olsen away from the roar of the drill site to the edge of the mesa. It overlooks a layer of petrified tree trunks, dusted white with ancient volcanic ash. Volcanoes often sprinkled ash here during the Triassic, and scientists can date that ash by counting uranium and lead atoms caged inside tiny, near-microscopic zircon crystals. The white layer below us has been dated at 210 million years, one of only a dozen or so hard dates obtained for the entire Petrified Forest. Olsen's collaborators will date thousands more zircons up and down the 1,600-foot core being drilled behind us.

If the Chinle cores yield a coherent sequence of dates, and if they agree with the Newark timeline, they could also shed light on the past and future movements of planets in our solar system.

"It would be nice if there's a smooth progression of ages down the hole," says Olsen. It would help them line up the Chinle and Newark cores and rebuff Lucas' criticisms. But ages in the core might also be scrambled, with older zircons layered above younger ones.

It is true in geology that rock equals time, but most rock is made of materials recycled from elsewhere on Earth. The badlands stretching out below Olsen and me originated from ancient mountain ranges in what are now Texas, California and Canada. Those mountains eroded, sending more than 1,000 cubic miles of sediment and older zircons tumbling down rivers and settling in the northern Arizona Chinle region over 200 million years ago, building the rocks we see here. Olsen's collaborators hope to sort out the zircon age problem by selectively dating ones with sharp rather than battered edges — those that came from the sky rather than a riverbed.

PLANETS IN MOTION

If the Chinle cores yield a coherent sequence of dates, and if they agree with the Newark timeline, they could also shed light on the past and future movements of planets in our solar system.

When Olsen studied his Newark cores in the mid-1990s, he noticed something odd. The Milankovitch cycles recorded in the rocks lined up well with those known in today's world, with one exception: A much longer cycle, marking a subtle gravitational tug-of-war between Mars and Earth, was off. Instead of 2.4 million years (as it is today), Olsen's cores showed the cycle lasted 1.75 million years. It was a hint that the movement of planets in our solar system hasn't always been what it is today.

When Olsen presented these results at a meeting in 1999, the man who followed him at the podium was visibly excited by what he had just seen. "That was exactly what I was proposing to do," he told the audience.

The man was Jacques Laskar, an astronomer at the Institute for Celestial Mechanics in Paris. He had spent a decade working on a 200-year-old problem: whether the planets' orbits are stable, or if they drift unpredictably over time.

Laskar's theoretical calculations for Mercury, Venus, Earth and Mars suggested the latter — that orbital deviations of just 50 feet will propagate to 240 million miles over 100 million years due to tiny shifts caused by gravitational tides in the planets' interiors and other factors. Now, Olsen had unexpectedly provided evidence that it could be true. The implications were breathtaking.

Laskar's analysis suggests that 1 billion to 3 billion years from now, Mercury could be tossed from its orbit, whereupon it might crash into the sun, slam into Venus or possibly even sling Mars onto a collision course with Earth, mashing our planet into a glob of molten rock.

The chances appear remote; Laskar's simulations show Mercury tossed from its orbit only 1 percent of the time. But other outcomes could still prove disastrous. Venus could go awry and crash into Mercury, unleashing millions of large fragments, some potentially colliding with Earth. And a near miss between Earth and Mars could cause much of the Martian crust to be ripped off by Earth's gravity, pulling thousands of meteors onto our planet.

This scary talk is speculative, but if the Chinle results match what Olsen and his team saw in Newark, those data on orbital variations could help Laskar better quantify the risk.

All of this remains a work in progress. The Chinle cores have already undergone CT scans to map their internal structure, and in February, Olsen and his colleagues began examining them in detail by eye — the first step in detecting evidence of Milankovitch cycles. Lucas, for his part, is surveying amphibian, crocodilian and dinosaur fossils found at over 800 sites across the western U.S. to refine his own timeline of when species appeared and vanished during the late Triassic.

Whichever timeline wins out — Olsen's or Lucas' — one thing is clear: Finding a way to measure deep time will shed light on all manner of questions from evolution to astronomy to eschatology, many of them not yet asked. ◼

Douglas Fox *is a writer whose work has also appeared in* Scientific American, Esquire *and the* Christian Science Monitor.