FEATURE | BY J. MADELEINE NASH

Back to the Future

The earth warmed considerably some 55 million years ago. What does that tell us about our current climate dilemma?

CLAMBERING onto a dun-colored knoll, not far from the small town of Worland, Wyo., Scott Wing stares out at the deeply abraded hills that sweep towards him like the waves of a vast stony ocean. "That's it," he says, pointing to a sinuous ribbon of rose-colored rock. "That's the Big Red." I follow his gaze, noting how the Big Red snakes into an arroyo, then disappears around a bend. Even to my untrained eye, the geological band seems to glow with a fierce, otherworldly intensity.

In some places, Wing explains, the Big Red is composed of multiple stripes; in others, it wends through the landscape as a single line of color. Then, too, the capricious hand of erosion has exposed it here, left it hidden over there. But after hours of pondering the pieces of this jigsaw, Wing, a paleobotanist at the Smithsonian's Museum of Natural History in Washington, D.C., believes he can now follow the Big Red for a distance of 25 miles, from the base of the solitary outcrop that looms in the distance all the way to the Sand Creek Divide.

The Sand Creek Divide is a high point in Wyoming's Big Horn Basin. From it you can see the emerald patchwork of irrigated sugar beet and malt barley fields that hug the Big Horn River as well as the jagged mountain ranges — the Absarokas, the Big Horns, the Owl Creeks — that define the edges of this harsh mid-latitude desert. Temperatures here regularly dip below 0 degrees Fahrenheit in wintertime and, in summer, soar well past 100. Away from waterways, the vegetation amounts to little more than a stippling of sagebrush intermingled with stands of invasive cheatgrass and ephemerally blooming wildflowers.

But between 55 and 56 million years ago, says Wing, the Big Horn Basin was a balmy, swampy Eden, teeming with flora and fauna that would be at home in today's coastal Carolinas. Crocodiles, turtles and alligator gar plied the waters of meandering rivers, and early mammals scampered through woodlands filled with the relatives of modern sycamores, bald cypresses and palms. And then, all of a sudden, things got a whole lot warmer. In a geological eye blink — less than 10,000 years, some think — global mean temperatures shot up by around 10 degrees Fahrenheit, jumpstarting a planetary heat wave that lasted for over 150,000 years.

Here, in the southeastern sector of the Basin, the Big Red is the most vivid marker of this exceptionally torrid time — the Paleocene-Eocene Thermal Maximum, or PETM, as most paleontologists call it. By following the Big Red, Wing and his colleagues hope to locate fossils and other clues that will help them reconstruct this long vanished world — a world with unexpected relevance for us as we hurtle towards our own rendezvous with climate change.

Scientists believe that, then as now, the earth warmed in response to a precipitous release of carbon dioxide and other heat-trapping gases, setting in motion events that reverberated through both marine and terrestrial ecosystems. But where did those gases come from so long ago? What triggered their sudden release? And, most important of all, how likely is it that the PETM, or something disquietingly close to it, could happen all over again?

In 1972, when a 17-year-old Wing made the first of many trips to the Big Horn Basin, scientists knew too little even to frame such questions. Today, however, dozens of paleontologists, oceanographers, geochemists and climate modelers are racing to come up with answers. Nowhere have they struck a more productive lode than in these candy-striped badlands. As Wing says, "You can literally walk up to a layer of rock and know that the Paleocene-Eocene boundary starts *here*."

Leaning on a long-handled shovel, Wing goes over the field schedule with a couple of colleagues, then heads back to Dino, a rust-colored 1970 Suburban with a bird-like dinosaur painted on each side. Wing bought this unlikely chariot in 1987 and somehow has kept it running ever since.

Five minutes later, he pulls up to the site that everyone refers to as "Ross's quarry" in honor of University of Nebraska paleontologist Ross Secord, who discovered it last year. Wing's crew has formed a conga line of shovelers, and as their 53-year-old leader scrambles up from below, they fling clouds of grit in his direction. Eventually, the pace of shoveling slows down so that promising chunks of rock can be individually examined and, if necessary, split open with a hammer. The best specimens are passed to Wing, who peers at each one through his eyepiece and decides whether to keep or discard it.

"This is a good one," Wing calls, so I

Like a time capsule, the leaf carries information that can illuminate what it was like to live in a rapidly warming world.

Scott Wing digs for PETM plant fossils in Wyoming's Big Horn Basin. Previous page, the Big Red, a visual marker of 55.5 million-year-old fossils.
THOMAS NASH

climb up to see. On the surface of the rock is an exquisitely formed leaf, its veins and margins perfectly preserved. Grayish brown in color and slightly dank, the 55-million-year-old leaf looks like it might have fallen last week and is just now beginning to molder. Adding to the illusion of freshness, its fossilized tissue retains traces of the waxes that once comprised its protective exterior coating.

The plant to which this leaf once belonged, Wing thinks, migrated from far to the south in response to warming temperatures. Like a time capsule, the leaf carries information that can illuminate what it was like to live in a rapidly warming world.

"So far, what we've learned is that processes we're now affecting are so complicated that we can't easily model them," Wing says. "We can monitor them, but over short periods of time there's so much noise in the system that it overwhelms the signal. That's why the geological and paleontological record is so important. It's one of the few ways we can look into how the system works." With that, Wing turns away to squint at another leaf. Unshaven, with a broad-brimmed hat squashed onto his head and a notebook stuffed into a field vest pocket, he looks just like the seasoned fossil hunter he is.

EVEN BEFORE IT HAD A NAME, the Paleocene-Eocene Thermal Maximum was starting to fascinate Wing. For some time, it had been clear to paleontologists studying the evolution of mammals that the transition between the Paleocene and the Eocene was marked by the kind of innovative burst that implies sweeping ecological change. Yet no hint of such a change had appeared in any of the fossil leaves Wing had collected. He would stare at leaves from the Paleocene and leaves from the Eocene, but see almost no difference between them. "It was getting to be annoying," he recalls.

The Paleocene is the geological epoch that started 65 million years ago, right after a wayward asteroid or comet crashed into the planet, ending the reign of the dinosaurs. At the time, mammals were rather simple, general-purpose creatures with few specializations: Their teeth, their ankle bones and joints all look extremely primitive. Then, barely 10 million years later, at the dawn of the Eocene, the first relatives of deer abruptly appear, along with the first primates and first horses.

"You can literally draw a line through the rock," says Philip Gingerich, a vertebrate paleontologist at the University of Michigan. "Above it there are horses; below it there aren't." In fact, where Gingerich works — at Polecat Bench, in the northern sector of the Big Horn Basin — you can actually see the line, in the form of a band of light gray sandstone. Oddly enough, many fossil mammals commonly found above this line, including those first horses, were abnormally small. Typically, Gingerich says, Eocene horses grew to the size of modern-day cocker spaniels, but these horses were "about the size of Siamese cats."

In 1991, as Gingerich and others were marveling over the miniature mammals of Polecat Bench, oceanographers James Kennett of the University of California, Santa Barbara, and Lowell Stott of the University of Southern California investigated a major extinction of small, shelly creatures that, during the late Paleocene, lived on the sea floor off the coast of Antarctica. This massive die-off, they found, coincided with a steep rise in deep ocean temperatures and a curious spike in atmospheric carbon.

Less than a year later, paleontologist Paul Koch and paleo-oceanographer James Zachos, both now at the University of California, Santa Cruz, teamed up with Gingerich to show that this geochemical glitch had also left its calling card on land. The trio established this indirectly by measuring the carbon content of fossilized teeth and nodules plucked from the Big Horn Basin's 55.5 million-year-old rocks.

To Wing, it began to seem increasingly implausible that plant communities could have segued through the PETM unaffected. So in 1994, he started a methodical search for the fossils that he was all but sure he had missed, returning year after year to the Big Horn Basin. He started in its southeastern corner and then moved north to explore Polecat Bench and the Clarks Fork Basin. Yet it wasn't until 2003, when he reached the Worland area, that he began to meet with success.

At first, he found just a smattering of leaves, too few to suggest any pattern. Then, in 2005, at the end of a long day, he slid his shovel into a grayish mound and pulled out a tiny leaf. "I knew immediately that this was totally different from anything I'd seen before, that this was really dramatic, so I got down on my knees and poked the shovel in again and then again. In every shovelful, there were more leaves coming out. First I started to laugh; then I started to cry. And then I looked up."

Staring down at Wing was a new field assistant. "He had a look on his face that said, 'Now I'm going to die.' I understood what he must have been thinking. 'Here I am, I've just graduated from college. I've never camped before. I've never been on a paleontological expedition before. It's 6 o'clock in the evening. It's still 100 degrees. I don't know where I am. And it looks like the boss has gone completely nuts!' So I said to him, 'Really, it's OK. I'm not crazy. It's just that I've been looking for this since you were 10 years old!' "

From that one site, Wing went on to extract more than 2,000 leaf fossils representing 30 different species. Missing from the mix are the cypresses and other conifers that were so common during the Paleocene; gone also are the distant cousins of broadleaf temperate zone trees like sycamores, dogwoods, birches. In their place are the legumes, a family of plants, shrubs and trees — think of acacias and mimosas —that thrive today in seasonally dry tropical and subtropical areas.

"What you see is almost a complete changeover from what was growing here before," Wing marvels. "What this means is that you could have stood in this one spot in Wyoming, surrounded by a forest, and everything would have looked pretty much the same for millions of years. And then, over a few tens of thousands of years, almost all the plants you're familiar with disappear and are replaced by plants you've never seen before in your life." At least some of the newcomers migrated north from as far away as the Mississippi Embayment, precursor of the Gulf of Mexico. With them came a wave of small but voracious predators: Many of the fossil leaves are peppered with the scars left by chewing, sucking, mining and boring insects.

By the time we realize we're in serious trouble, in other words, it may be too late to do much about it.

IT'S A COOL, CLEAR MORNING, with just a few wisps of cirrus streaking the sky, when Francesca Smith settles into a spot just above Ross's quarry, sitting cross-legged on the crackled ground. Across the road, along the ridgeline, are three petroleum pump jacks, their heads slowly rising and dipping as underground reservoirs empty, then fill with oil.

An associate professor at Northwestern University, the bubbly, brown-haired geochemist arrived only yesterday, having driven herself and two young assistants out from Illinois. Wing hands her a slab of mudstone. "Look," he says, pointing to the merest fragment of a leaf splayed across the surface. "That's a little piece of organic matter — it's probably part of the cuticle." At that moment, the wind picks up, and the paper-thin specimen peels back from the rock, threatening to fly away. "Emergency wrap!" Smith shouts, hastily enfolding her prize in an envelope of foam.

For a moment, Smith contemplates the pump jacks, visual metaphors linking the prehistoric world she and Wing are exploring to our world's present and future. The carbon released during the PETM, she notes, is also thought to have come from organic sources, just like the carbon we pump into the atmosphere every time we turn on a light or drive a car. "The only difference," Smith reflects, "is that we're doing it much, much faster."

During the Paleocene-Eocene Thermal Maximum, scientists estimate that a massive amount of carbon — 4 to 5 trillion metric tons, perhaps — flooded into the atmosphere. That's about 10 times more carbon than humans have pumped

Scott Wing and his crew trek up a ridge of vivid red paleosols in the Big Horn Basin. Below, Doug Boyer examines a mammal fossil while a pump-jack works nearby. THOMAS NASH

out since 1751, and the rough equivalent of how much carbon remains stored in fossil fuels.

From a climatological perspective, it makes sense that the infusion of that much carbon would jack up temperatures. After all, carbon combines with oxygen to form carbon dioxide, which, next to water vapor, is the most abundant of the planet's greenhouse gases. As their name suggests, these gases (which also include methane and nitrous oxide) behave rather like the transparent panes of a greenhouse: They allow the sun's rays to stream in but trap a good deal of the heat the earth beams back in response.

In general, this is a good thing; it helps create what some call the Goldilocks effect — the fact that, to human beings and other creatures, Earth's temperature seems "just right," neither hellishly hot like Venus nor bitterly cold like Mars. That's not to say that our planet's pane of greenhouse gases never varies in thickness. Ancient air bubbles trapped in Antarctica's ice show that levels of carbon dioxide declined during past Ice Ages and rose during warm interglacials such as our own.

It's not clear how much carbon dioxide there was in the atmosphere on the eve of the PETM, but scientists think levels may have reached somewhere between 500 and 750 parts per million. This compares to 380 parts per million at present, 280 parts per million in pre-industrial times, and 180 during past glacial high stands. As a result, the late Paleocene was already quite warm, about as warm as many climatologists project our world could become by the start of the next century.

The large amount of carbon dioxide in the pre-PETM atmosphere almost certainly came from a sustained spate of volcanic eruptions. (During the Paleocene, volcanoes were particularly active.) As a result, the atmosphere's load of carbon dioxide gradually rose. Then, around 55.5 million years ago, carbon dioxide levels shot up very sharply, perhaps to 1,800 or more parts per million, leaving behind a distinctive geochemical signature.

The signature, Smith explains, takes the form of a dramatic shift in the ratio between two stable forms of carbon, heavier carbon-13 and lighter carbon-12. It's this shift that scientists first picked up in the calcareous shells of marine organisms, then found in the teeth of terrestrial mammals. Last year, Smith and Wing showed that, in the Big Horn Basin, the shift is captured by leaf waxes as well. "And there is only one way we know of to shift the ratio as much as it shifted," Smith says, "and that's to add a lot more light carbon."

The richest concentrations of light carbon are found in organic materials, including fossil fuels like coal (which forms from deeply buried plants) and methane gas (primarily a byproduct of microbial decomposition). While scientists are still not sure what triggered the massive release of light carbon at the start of the PETM, they do have a number of possible culprits, including fires that raged though forests, dried-up peat bogs and even underground coal seams, and effusively erupting volcanoes whose magma intruded into organic-rich sediments, cooking out the carbon.

Of all the scenarios so far floated, perhaps the most provocative invokes the dissolution of methane hydrates on the seafloor. These are ice-like solids in which water molecules form crystalline cages that entrap molecules of gas; they form, and remain stable, within specific ranges of temperature and pressure. At the end of the Paleocene, Rice University earth scientist Gerald Dickens has suggested, a jolt of warmth from an unknown source pushed these strange solids to the point that the methane gas inside them started burbling up through the ocean and into the atmosphere.

Methane is much shorter-lived than carbon dioxide, but it's also a more effective greenhouse gas. And as methane breaks down, the carbon it contains recombines with oxygen to form carbon dioxide, which can circulate through the climate system for thousands of years.

After serious study, many experts have concluded that not enough methane was locked up in hydrate form to have single-handedly caused the PETM. That does not constitute an absolution, however. A big release of seafloor methane could still have been part of a sustained chain reaction whereby an initial rise in carbon caused enough warming to trigger the release of additional carbon that caused still more warming, and so on. Might the carbon we are so heedlessly pumping out today spark a similar sequence of events?

As scientists try to imagine the consequences of our greenhouse gas emissions, they invariably return to this question. The earth abounds with "traps" for carbon — not just seafloor hydrates, but also terrestrial forests, marine plankton and frozen Arctic soils. Some of these our own warming climate may already be springing open. Scientists from the University of Alaska, Fairbanks recently calculated that the permafrost of the far North sequesters 100 billion tons of carbon in its top three feet alone; as the permafrost thaws, that carbon will progressively leak into the atmosphere.

The release of carbon from some of these traps will be offset by the uptake of carbon in others. But at some point, scientists worry, the release of carbon may so far outweigh its absorption that the situation will cascade out of control. By the time we realize we're in serious trouble, in other words, it may be too late to do much about it.

INSIDE A CAVERNOUS TENT bathed in golden late-afternoon light, the resident team of vertebrate paleontologists pores over the day's haul, emitting sporadic whoops of surprise. "That might be a eureka," exclaims Yale University graduate student Stephen Chester, peering through a microscope at a tooth embedded in a jawbone fragment. "That might be a primate."

"It is! It's totally *Teilhardina!*" Doug Boyer, a Ph.D. candidate at New York's Stony Brook University, enthusiastically agrees. *Teilhardina*, he explains, is the Latin name for a group of primates that appear in Asia, Europe and North America at roughly the same time.

"That's a horse, Douggie," Chester says, examining another tooth. It belongs to *Hyracotherium sandrae*, the unusually small species first identified at Polecat Bench. The tooth is a shiny dark amber and it's very tiny. Why *was* this horse, *Hyracotherium sandrae,* so small?

The most straightforward explanation is that *Hyracotherium sandrae* was simply a small-sized species that migrated into the Big Horn Basin from somewhere else. But the University of Michigan's Gingerich champions a more intriguing possibility. He suggests that its diminutive stature could be the consequence of a decline in available nutrients, notably protein. Horticultural experiments have shown that some plants, when bathed in high concentrations of carbon dioxide, have less protein in their leaves.

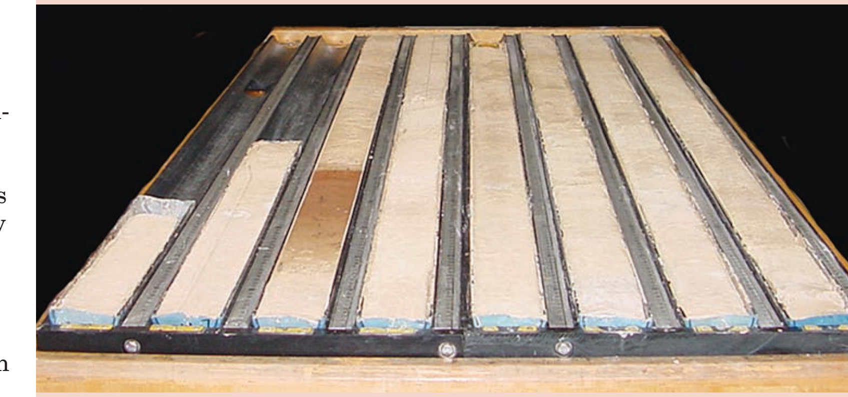
The same phenomenon may also have caused insects to become more voracious, which is consistent with the leaf damage displayed by Wing's fossils. Here again, however, there are other possible explanations. For example, higher temperatures alone would have raised insect food requirements by quickening metabolic rates and encouraging year-round breeding. "During the PETM, many things are changing all at once, and it's hard to separate one from another," Wing observes.

At present, Wing is in the field camp's cooking tent, heating up his favorite utensil, a big black wok that can handle dinner for 16. Just behind him, seated at a long metal table, Mary Kraus, a wiry sedimentologist from the University of Colorado, is starting to peel a big pile of russet potatoes. She and her daughter, Christina, have had a great day, she says, digging a trench through the pastel paleosols of the badlands surrounding a perennially dry fork of Nowater Creek. "Look at this treasure," she exclaims, holding up a fossilized insect burrow shaped vaguely like a cowboy's boot.

Like tree rings and deep sea sediments, burrows are what scientists refer to as "proxies." Simply put, proxies are natural systems that record and preserve information about past climates, not unlike modern instruments. Crayfish burrows indicate soils that experience large fluctuations in wetness; earthworm and beetle burrows suggest drier conditions. The colors of ancient soils are also proxies. For example, the degree of redness — whether the color tends towards orange or towards purple — can be correlated with specific ranges of soil moisture.

There are many other types of proxies, including fossil leaves, teeth and the shells of marine organisms. Typically these proxies record shifts in the ratio between heavy and light elements. Oxygen shifts can be translated into temperature; hydrogen

See Climate Disaster, page 27



Core samples from the South Atlantic show the typical pale-colored sediment indicative of a healthy carbonate-rich seafloor, interrupted by a dark-colored band of clay, representing a blip in geologic time of 100,000 years, when the ocean was highly acidic, about 55 million years ago. COURTESY JAMES ZACHOS, UC-BERKELEY

Acidifying oceans

James Zachos fishes around his desk and pulls out a plastic bag filled with chunks of deep-sea sediments. The sediments, wrested from the South Atlantic in 2003, are 55.5 million years old and deep red in color because they are almost entirely clay. Missing is the abundance of shelly residue that gives abyssal sediments their typically pallid complexions. "This is what you end up with when the ocean is being acidified," the University of California, Santa Cruz, paleo-oceanographer says.

The acidification, he explains, was a byproduct of the ocean's stalwart performance as regulator of the planet's geochemistry. As carbon dioxide rises in the atmosphere, the ocean mops up much of the excess. Over the past two centuries, scientists estimate that its vast blue waters have absorbed something like 40 percent of the carbon dioxide we've thus far emitted. But this assist to the atmosphere comes at a price. In water, carbon dioxide turns into carbonic acid, the same weak corrosive found in soft drinks.

During the PETM, the ocean contained enough carbonic acid to make life difficult for many shell-building organisms. At times, shells may have dissolved as fast as marine organisms could construct them. Among those most affected, Zachos thinks, were benthic foraminifera or forams, bottom-dwelling organisms the size of sand grains. During this tumultuous time, more than 30 percent of benthic foram species are thought to have gone extinct.

Today, the ocean is already less alkaline than in pre-industrial times, by about 0.1 units of pH. Some 55 million years ago, the pH shift was more extreme, in the neighborhood of 0.4 units. But, says Zachos, we are now on track to surpass that shift by the start of the next century and to double it by the year 2300. If that happens, the pH of the global ocean, currently around 8.0, will ever more closely approach 7.0, the dividing line between alkalinity and acidity.

More than anything, it's the rate of change that has scientists worried. It's one thing to add a big load of carbon dioxide to the ocean over a few millennia, quite another to shock the ocean by adding a similar amount in just a few centuries. "We do not know with certainty what the consequences will be," says Ken Caldeira, a climate expert with the Carnegie Institution Department of Global Ecology at Stanford University. "But we are now adding carbon so fast that, chances are, the disturbance to the ocean will be even more extreme."

Eventually, of course, the ocean of 55.5 million years ago recovered. Rain falling on the land slowly weathered rock into acid-buffering compounds, which washed into rivers that emptied into the seas. The rebound is visually apparent, Zachos says, projecting a slide that shows the sedimentary sequence. And there it is, the color change — from red to beige — that marks the end of one disturbing chapter in our planet's history.

—J. MADELEINE NASH

continued from page 19

Who would have predicted that over so few centuries, the descendants of Eocene primates would become so dependent on carbon-based fuels as to unbalance the planet?

shifts into relative humidity. Changes in leaf size and shape can likewise be read as proxies for temperature and moisture, though as Wing admits, "We don't fully understand why."

Multiple proxies, Wing says, suggest that, during the PETM, this area of Wyoming was rather similar to South Florida, with a mean annual temperature of around 75 degrees F and annual precipitation between 30 and 55 inches. The precipitation may have followed a strongly seasonal pattern, especially towards the beginning, with part of the year being quite dry, Wing believes. But that's just the broad-brush picture. Wing, Smith and Kraus, along with University of Florida paleontologist Jonathan Bloch, who heads up the vertebrate fossil collection effort, are working on reconstructing the regional climate in much finer detail.

Kraus is using ancient soils to begin mapping what seems like a climatological progression. The initial phase of the PETM looks rather dry, she says, and the middle phase appears drier still, though there are signs of very rapid soil deposition from flooding along rivers and streams. Towards the end of the PETM, in the Big Red itself, she is finding hints that conditions may have become wetter. Among other things, the rocks of the Big Red contain a lot of purple, a color suggestive of higher water tables and more poorly drained soils.

The Big Horn Basin, Kraus says, is probably the ideal place to try to pull together a comprehensive picture of how climate changed on a regional scale over the course of the PETM. "Where else can you go and find 5,000 year intervals stacked one on top of another?" she asks. "Where else can you go and know that 40 meters of rock (about 130 feet) equals 150,000 years?" That's around how long it took the PETM to wind up and wind down, so it's not surprising that, over the course of so many millennia, both regional and global climate patterns underwent successive changes. The wind-up, of course, was the fast part; it was the wind-down that took a long time.

DELICIOUS AROMAS ARISE from the wok as Wing adds onions and garlic and ginger. Following their noses, the vertebrate fossil crew streams in. Soon we are all sitting in camp chairs, chowing down on rice and spicy curry. After dinner, when the dishes are all washed, dried and put away, Wing pulls out the battered acoustic guitar he bought for $8 years ago in a Worland pawn shop. He starts strumming it softly. Two more members of the group join in, one on a battery-powered keyboard, the other on a tinny guitar.

As the trio warbles out a medley of familiar songs, I contemplate the gossamer sash of the Milky Way as it flows across the nighttime sky. The universe is almost 14 billion years old. Some of the stars in our galaxy are 10 billion years old. The earth and the sun it circles are around 4.5 billion years old. Measured against such a long stretch of time, the duration of the Paleocene-Eocene Thermal Maximum seems absurdly insignificant. Compared to our own allotment of some few score years and ten, however, it looms a great deal larger. In little more than 150,000 years, ice ages came and went and started anew. In 150,000 years, modern humans diverged from their archaic ancestors and began to spread across the world.

For most of that time, our forebears lived in small, mobile clusters of hunter-gatherers. They began coalescing into settled agricultural communities perhaps 10,000 years ago. Their history as members of a technologically advanced industrial civilization is breathtakingly recent, powered into existence by the 18th century invention of efficient coal-fired steam engines. Who would have predicted that over the span of so few centuries, the clever, adaptable descendants of Eocene primates would become so numerous — and so dependent on carbon-based fuels — as to unbalance the planet?

Perhaps, many hundreds of thousands of years from now, paleontologists from some advanced civilization will uncover fossils from our world and marvel at the carbon shift recorded by the teeth of free-ranging cattle and sheep, and the leaves of garden shrubs and trees. Will those beings fathom the real wonder of our story, the fact that we had glimmers of what the future held and yet failed to use that knowledge? Or will our story, like one of Shakespeare's dark comedies, work its way to a happier ending?

It's not that the PETM offers a precise road map to our future, Wing says, when I ask for his thoughts. "It's more that it's an example of the surprises that are waiting for us out there. How was it that Mark Twain put it? History does not repeat itself, but it sure does rhyme." □

Cataloging the day's finds in the vertebrate paleontologists' tent are, clockwise from bottom: Katie Slivensky, Sara Parent, Stephen Chester, Doug Boyer, Paul Morse. THOMAS NASH