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The Terrifying Warning Lurking in the Earth's Ancient Rock Record

Our climate models could be missing something big.

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We live on a wild planet, a wobbly, erupting, ocean-sloshed orb that careens around a giant thermonuclear explosion in the void. Big rocks whiz by overhead, and here on the Earth's surface, whole continents crash together, rip apart, and occasionally turn inside out, killing nearly everything. Our planet is fickle. When the unseen tug of celestial bodies points Earth toward a new North Star, for instance, the shift in sunlight can dry up the Sahara, or fill it with hippopotamuses. Of more immediate interest today, a variation in the composition of the Earth's atmosphere of as little as 0.1 percent has meant the difference between sweltering Arctic rainforests and a half mile of ice atop Boston. That negligible wisp of the air is carbon dioxide.

Since about the time of the American Civil War, CO_2's crucial role in warming the planet has been well understood. And not just based on mathematical models: The planet has run many experiments with different levels of atmospheric CO_2. At some points in the Earth's history, lots of CO_2 has vented from the crust and leaped from the seas, and the planet has gotten warm. At others, lots of CO_2 has been hidden away in the rocks and in the ocean's depths, and the planet has gotten cold. The sea level, meanwhile, has tried to keep up—rising and falling over the ages, with coastlines racing out across the continental shelf, only to be drawn back in again. During the entire half-billion-year Phanerozoic eon of animal life, CO_2 has been the primary driver of the Earth's climate. And sometimes, when the planet has issued a truly titanic slug of CO_2 into the atmosphere, things have gone horribly wrong.

Today, humans are injecting CO_2 into the atmosphere at one of the fastest rates ever over this entire, near-eternal span. When hucksters tell you that the climate is always changing, they're right, but that's not the good news they think it is. "The climate system is an angry beast," the late Columbia climate scientist Wally Broecker was fond of saying, "and we are poking it with sticks."

The beast has only just begun to snarl. All of recorded human history—at only a few thousand years, a mere eyeblink in geologic time—has played out in perhaps the most stable climate window of the past 650,000 years. We have been shielded from the climate's violence by our short civilizational memory, and our remarkably good fortune. But humanity's ongoing chemistry experiment on our planet could push the climate well beyond those slim historical parameters, into a state it hasn't seen in tens of millions of years, a world for which *Homo sapiens* did not evolve.

When there's been as much carbon dioxide in the air as there already is today—not to mention how much there's likely to be in 50 or 100 years—the world has been much, much warmer, with seas 70 feet higher than they are today. Why? The planet today is not yet in equilibrium with the warped atmosphere that industrial civilization has so recently created. If CO_2 stays at its current levels, much less steadily increases, it will take centuries—even millennia—for the planet to fully find its new footing. The transition will be punishing in the near term and the long term, and when it's over, Earth will look far different from the one that nursed humanity. This is the grim lesson of paleoclimatology: The planet seems to respond far more aggressively to small provocations than it's been projected to by many of our models.

To truly appreciate the coming changes to our planet, we need to plumb the history of climate change. So let us take a trip back into deep time, a journey that will begin with the familiar climate of recorded history and end in the feverish, high-CO_2 greenhouse of the early age of mammals, 50 million years ago. It is a sobering journey, one that warns of catastrophic surprises that may be in store.

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The first couple of steps back in time won't take us to a warmer world—but they will illuminate just what sort of ill-tempered planet we're dealing with. As we pull back even slightly from the span of recorded history—our tiny sliver of geologic time—we'll notice almost at once that the entire record of human civilization is perched at the edge of a climate cliff. Below is a punishing ice age. As it turns out, we live on an ice-age planet, one marked by the swelling and disintegration of massive polar ice sheets in response to tiny changes in sunlight and CO_2 levels. Our current warmer period is merely one peak in a mountain range, with each summit an interglacial springtime like today, and each valley floor a deep freeze. It takes some doing to escape this cycle, but with CO_2 as it is now, we won't be returning to an ice age for the foreseeable future. And to reach analogues for the kind of warming we'll likely see in the coming decades and centuries, we will need to move beyond the past 3 million years of ice ages entirely, and make drastic jumps back into the alien Earths of tens of millions of years ago. Our future may come to resemble these strange lost worlds.

Before we move more dramatically backwards in time, let us briefly pause over the history of civilization, and then some. Ten thousand years ago, the big mammals had just vanished, at human hands, in Eurasia and the Americas. Steppes once filled with mammoths and camels and wetlands stocked with giant beavers were suddenly, stunningly vacant.

The coastlines that civilization presumes to be eternal were still far beyond today's horizon. But the seas were rising. The doomed vestiges of mile-thick ice sheets that had cloaked a third of North American land were retreating to the far corners of Canada, chased there by tundra and taiga. The roughly 13 quintillion gallons of meltwater these ice sheets would hemorrhage, in a matter of millennia, raised the sea level hundreds of feet, leaving coral reefs that had been bathed in sunlight under shallow waves now drowned in the deep.

By 9,000 years ago, humans in the Fertile Crescent, China, Mexico, and the Andes had independently developed agriculture and—after 200,000 years of wandering—had begun to stay put. Sedentary settlements blossomed. Humans, with a surfeit of calories, began to divide their labor, and artisans plied new arts. The Earth's oldest cities, such as Jericho, were bustling.

By 5,000 years ago, sunlight had waned in the Northern summer, and rains drifted south toward the equator again. The green Sahara began to die, as it had many times before.

It's easy to forget that the Earth—cozy, pastoral, familiar—is nevertheless a celestial body, and astronomy still has a vote in earthly affairs. Every 20,000 years or so the planet swivels about its axis, and 10,000 years ago, at civilization's first light, the Earth's top half was aimed toward the sun during the closest part of its orbit—an arrangement today enjoyed by the Southern Hemisphere. The resulting Northern-summer warmth turned the Sahara green. Lakes, hosting hippos, crocodiles, turtles, and buffalo, speckled North Africa, Arabia, and everywhere in between. Lake Chad, which today finds itself overtaxed and shrinking toward oblivion, was "Mega-Chad," a 115,000-square-mile freshwater sea that sprawled across the continent. Beneath the Mediterranean today, hundreds of dark mud layers alternate with whiter muck, a barcode that marks the Sahara's rhythmic switching from lush green to continent-spanning desert.

Imprinted on top of this cycle were the last gasps of an ice age that had gripped the planet for the previous 100,000 years. The Earth was still thawing, and amid the final approach of the rising tides, enormous plains and forests like Doggerland—a lowland that had joined mainland Europe to the British Isles—were abandoned by nomadic humans and offered to the surging seas. Vast islands like Georges Bank, 75 miles off Massachusetts—which once held mastodons and giant ground sloths—saw their menagerie overtaken. Scallop draggers still pull up their tusks and teeth today, far offshore.

By 5,000 years ago, as humanity was emerging from its unlettered millennia, the ice had stopped melting and oceans that had been surging for 15,000 years finally settled on modern shorelines. Sunlight had waned in the Northern summer, and rains drifted south toward the equator again. The green Sahara began to die, as it had many times before. Hunter-fisher-gatherers who for thousands of years had littered the verdant interior of North Africa with fishhooks and harpoon points abandoned the now-arid wastelands, and gathered along the Nile. The age of pharaohs began.

By geologic standards, the climate has been remarkably stable ever since, until the sudden warming of the past few decades. That's unsettling, because history tells us that even local, trivial climate misadventures during this otherwise peaceful span can help bring societies to ruin. In fact, 3,200 years ago, an entire network of civilizations—a veritable globalized economy—fell apart when minor climate chaos struck.

"There is famine in [our] house; we will all die of hunger. If you do not quickly arrive here, we ourselves will die of hunger. You will not see a living soul from your land." This letter was sent between associates at a commercial firm in Syria with outposts spread across the region, as cities from the Levant to the Euphrates fell. Across the Mediterranean and Mesopotamia, dynasties that had ruled for centuries were all collapsing. The mortuary-temple walls of Ramses III—the last great pharaoh of Egypt's New Kingdom period—speak of waves of mass migration, over land and sea, and warfare with mysterious invaders from afar. Within decades the entire Bronze Age world had collapsed.

Historians have advanced many culprits for the breakdown, including earthquakes and rebellions. But like our own teetering world—one strained by souring trade relations, with fractious populaces led by unsteady, unscrupulous leaders and now stricken by plague—the eastern Mediterranean and the Aegean were ill-prepared to accommodate the deteriorating climate. While one must resist environmental determinism, it is nevertheless telling that when the region mildly cooled and a centuries-long drought struck around 1200 B.C., this network of ancient civilizations fell to pieces. Even Megiddo, the biblical site of Armageddon, was destroyed.

This same story is told elsewhere, over and over, throughout the extremely mild stretch of time that is written history. The Roman empire's imperial power was vouchsafed by centuries of warm weather, but its end saw a return to an arid cold—perhaps conjured by distant pressure systems over Iceland and the Azores. In A.D. 536, known as the worst year to be alive, one of Iceland's volcanoes exploded, and darkness descended over the Northern Hemisphere, bringing summer snow to China and starvation to Ireland. In Central America several centuries later, when the reliable band of tropical rainfall that rings the Earth left the Mayan lowlands and headed south, the megalithic civilization above it withered. In North America, a megadrought about 800 years ago made ancestral Puebloans abandon cliffside villages like Mesa Verde, as Nebraska was swept by giant sand dunes and California burned. In the 15th century, a 30-year drought bookended by equally unhelpful deluges brought the Khmer at Angkor low. The "hydraulic empire" had been fed and maintained by an elaborate irrigation system of canals and reservoirs. But when these canals ran dry for decades, then clogged with rains, invaders easily toppled the empire in 1431, and the Khmer forfeited their temples to the jungle.

Hopscotching through these human disasters to the present day, we pass perhaps the most familiar historical climate event of all: the Little Ice Age. Lasting roughly from 1500 to 1850, the chill made ice rinks of Dutch canals, and swelled up Swiss mountain glaciers. Tent cities sprung up on a frozen Thames, and George Washington endured his winter of cold and privation at Valley Forge in 1777 (which wasn't even particularly harsh for the times). The Little Ice Age might have been a regional event, perhaps the product of an exceptional run of sunlight-dimming volcanism. In 1816, its annus horribilis, the so-called year without a summer—which brought snows to New England in August—global temperatures dropped perhaps a mere half a degree Celsius. While it is perennially plumbed by historians for insights into future climate change, it is not even remotely on the same scale of disruption as that which might lie in our future.

As Europe emerged from its chill, coal from 300-million-year-old jungles was being fed into English furnaces. Although the Earth was now in the same configuration that, in the previous few million years, had invited a return to deep, unthinkable ice ages, for some reason the next ice age never took. Instead the planet embarked on an almost unprecedented global chemistry experiment. Halfway through the 20th century, the climate began behaving very strangely.

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So this is the climate of written history, a seemingly eventful stretch that has really been the random noise and variability of a climate essentially at peace. Indeed, if you were to find yourself in an industrial civilization somewhere else in the universe, you would almost certainly notice such similarly strange and improbably pleasant millennia behind you. This kind of climate stability seems to be a prerequisite for organized society. It is, in other words, as good as it gets.

As we jump back 20,000 years—to yesterday, geologically—the world ceases being recognizable. Whereas all of recorded history played out in a climate hovering well within a band of 1 degree Celsius, we now see what a difference 5 to 6 degrees can make—a scale of change similar to the one that humans may engineer in only the next century or so, though in this case, the world is 5 to 6 degrees colder, not warmer.

An Antarctica's worth of ice now rests atop North America. Similar sheets smother northern Europe, and as a result, the sea level is now 400 feet lower. The midwestern United States is carpeted in stands of stunted spruce of the sort that would today look at home in northern Quebec. The Rockies are carved up, not by wildflower-dappled mountain valleys, but by overflowing rivers of ice and rock. California is a land of dire wolves. Where the Pacific Northwest edges up against the American Antarctica, it is a harsh and treeless place. Nevada and Utah fill up with cold rains.

During World War II, at Topaz, the desolate Japanese American internment camp in Utah, prisoners combed the flats of the Sevier Desert for unlikely seashells, fashioning miraculous little brooches from tiny mussel and snail shells to while away their exile. The desert seashells were roughly 20,000 years old, from the vanished depths of the giant Pleistocene-era Lake Bonneville—the product of a jet stream diverted south by the ice sheet. This was once a Utahan Lake Superior, more than 1,000 feet deep in places. It was joined by endless other verdant lakes scattered across today's bleak Basin and Range region.

Elsewhere, the retreat of the seas made most of Indonesia a peninsula of mainland Asia. Vast savannas and swamps linked Australia and New Guinea, and of course Russia shared a tundra handshake with Alaska. There were reindeer in Spain, and glaciers in Morocco. And everywhere loess, loess, and more loess. This was the age of dust.

Ice is a rock that flows. Send it in massive sterilizing slabs across the continents, and it will quarry mountainsides, pulverize bedrock, and obliterate everything in its path. At the height of the last ice age, along the crumbling margins of the continental ice sheets, the rocky, dusty spoils of all this destruction spilled out onto the tundra. Dry winds carried this silt around the world in enormous dust storms, piling it up in seas of loess that buried the central U.S., China, and Eastern Europe under featureless drifts. In Austria, not far from the site of the voluptuous Venus of Willendorf figurine, carved some 30,000 years ago, are the remains of a campground of the same age—tents, hearths, burnt garbage pits, hoards of ivory jewelry—all abandoned in the face of these violent, smothering haboobs. Ice cores from both Antarctica and Greenland record a local environment that was 10 times dustier than today. All of this dust seeded the seas with iron, a vital nutrient for carbon-hogging plankton, which bloomed around Antarctica and pulled gigatons of CO_2 out of the air and deep into the ocean, freezing the planet further.

Read: When a killer climate catastrophe struck the world's oceans

This parched Pleistocene world would have appeared duller from space, hosting as it did a quarter less plant life. CO_2 in the atmosphere registered only a paltry 180 ppm, less than half of what it is today. In fact, CO_2 was so low, it might have been unable to drop any further. Photosynthesis starts to shut down at such trifling levels, a negative-feedback effect that might have left more CO_2—unused by plants—in the air above, acting as a brake on the deep freeze.

This was the strange world of the Ice Age, one that, geologically speaking, is still remarkably recent. It's so recent, in fact, that today, most of Canada and Scandinavia is still bouncing back up from the now-vanished ice sheets that had weighed those lands down.

The floods carried 30-foot boulders on biblical waves, through what were suddenly the world's wildest rapids.

In 2021, we find ourselves in an unusual situation: We live on a world with massive ice sheets, one of which covers one of the seven continents and is more than a mile deep. For most of the planet's past, it has had virtually no ice whatsoever. The periods of extreme cold—like the ultra-ancient, phantasmagoric nightmares of Snowball Earth, when the oceans might have been smothered by ice sheets all the way to the tropics—are outliers. There were a few other surprising pulses of frost here and there, but they merely punctuate the balmy stretches of the fossil record. For almost all of the Earth's history, the planet was a much warmer place than it is today, with much higher CO_2 levels. This is not a climate-denying talking point; it's a physical fact, and acknowledging it does nothing to take away from the potential catastrophe of future warming. After all, we humans, along with everything else alive today, evolved to live in our familiar low-CO_2 world—a process that took a long time.

How long, exactly? Fifty million years ago, as our tiny mammalian ancestors were still sweating through the jungly, high-CO_2 greenhouse climate they had inherited from the dinosaurs, India was nearing the end of an extended journey. Long estranged from Africa and the august, bygone supercontinent of Gondwana, the subcontinent raced northeast across the proto–Indian Ocean and smashed into Asia in slow motion. The collision not only quieted CO_2-spewing volcanoes along Asian subduction zones; it also thrust the Himalayas and the Tibetan Plateau toward the stars, to be continually weathered and eroded away.

As it turns out, weathering rocks—that is, breaking them down with CO_2-rich rainwater—is one of the planet's most effective long-term mechanisms for removing carbon dioxide from the atmosphere, one that modern geoengineers are frantically trying to reproduce in a lab, for obvious reasons.

Adding to this colossal Himalayan CO_2 sink, the more recent buckling, tectonic mess that lifted Indonesia and its neighbors from the sea over the past 20 million years or so also exhumed vast tracts of highly weatherable ocean crust, exposing it all to the withering assault of tropical rainstorms. Today this corroding rock accounts for roughly 10 percent of the planet's carbon sink. Over tens of millions of years, then, the stately march of plate tectonics—the balance of volcanic CO_2 and rock weathering—seems to have driven long-term climate change, in our case toward a colder, lower-CO_2 world. As we'll see, humans now threaten to undo this entire epic, geologic-scale climate evolution of the Cenozoic era—and in only a few decades.

When Earth's blanket of CO_2 was finally thin enough, the planet's regular wobbles were at long last sufficient to trigger deep glaciations. The ice ages began. But the climate was not stable during this period. The ice advanced and retreated, and while the descent into the wild episodes of the Pleistocene epoch could be leisurely—the depths of planetary winter taking tens of thousands of years to arrive—the leap out of the cold tended to be sudden and violent. This is where positive feedback loops come in: When the last ice age ended, it ended fast.

Coral reefs marking the ancient sea level—but today lying deep off the coasts of Tahiti and Indonesia—reveal that about 14,500 years ago, the seas suddenly jumped 50 feet or so in only a few centuries, as meltwater from the late, great North American ice sheet raged down the Mississippi. When a 300-foot-deep lake of glacial meltwater spanning at least 80,000 square miles of central Canada catastrophically drained into the ocean, it shut down the churn of the North Atlantic and arrested the seaborne flow of heat northward. As a result, tundra advanced to retake much of Europe for 1,000 years. But when ocean circulation kicked back into gear, and the dense, salty seawater began to sink again, the system rebooted, and currents carried the equator's heat toward the Arctic once more. Temperatures in Greenland suddenly leaped 10 degrees Celsius in perhaps a decade, fires spread, and revanchist forests reclaimed Europe for good.

In Idaho, ice dams that had held back giant lakes of glacial meltwater about six times the volume of Lake Erie collapsed as the world warmed, and each released 10 times the flow of all the rivers on Earth into eastern Washington. The floods carried 30-foot boulders on biblical waves, through what were suddenly the world's wildest rapids. They left behind a labyrinth of bedrock-scoured canyons that still covers the entire southeastern corner of the state like a scar. When the Earth's climate changes, this is what it can look like on the ground.

As the ice sheets of the Northern Hemisphere finally lost their grip, darker land around the melting margins became exposed to the sun for the first time in 100,000 years, accelerating the ice's retreat. Permafrost melted, and methane bubbled up from thawing bogs. Colder, more CO_2-soluble oceans warmed, and gave up the carbon they'd stolen in the Ice Age, warming the Earth even more. Relieved of their glacial burden, volcanoes in Iceland, Europe, and California awoke, adding even more CO_2 to the atmosphere.

Soon the Sahara would green again, Jericho would be born, and humans would start writing things down. They would do so with the assumption that the world they saw was the way it had always been. "We were born only yesterday and know nothing," one of them would write. "And our days on earth are but a shadow."

As we leap back in time again, we emerge before the final Pleistocene glaciation. We've gone tremendously far back, 129,000 years, though in some ways we've only returned to our own world. This was the most recent interglacial period, the last of many breaks between the ice ages, and the last time the planet was roughly as warm as it is today. Once more, the seas have risen hundreds of feet, but something is awry.

As the Earth's wobble and orbit conspired to melt more ice than the poles have shed so far today, the planet absorbed more sunlight. As a result, global temperatures were little more than 1 degree warmer than today's Anthropocene chart-toppers—or maybe even the same. But sea level was 20 to 30 feet higher than it is now. (A full third of Florida was sunk beneath the waves.) This is "sobering," as one paper put it.

Modelers have tried and mostly failed to square how a world about as warm as today's could produce seas so strangely high. Provisional, if nightmarish, explanations like the runaway, catastrophic collapse of monstrous ice cliffs more than 300 feet tall in Antarctica, which may or may not be set into motion in our own time, are fiercely debated in conference halls and geoscience departments.

Very soon, we may well have warmed the planet enough to trigger similarly dramatic sea-level rise, even if it takes centuries to play out. This is what the Exxon scientist James Black meant in 1977 when he warned higher-ups of the coming "super-interglacial" that would be brought about—as a matter of simple atmospheric physics—from burning fossil fuels. But our trajectory as a civilization is headed well beyond the warmth of the last interglacial, or any other interglacial period of the Pleistocene, for that matter. So it's time to keep moving. We must take our first truly heroic leap into geologic time, millions of years into the past.

We're more than 3 million years in the past now, and carbon dioxide in the atmosphere is at 400 parts per million, a level the planet will not again see until September 2016. This world is 3 to 4 degrees Celsius warmer than ours, and the sea level is up to 80 feet higher. Stunted beech trees and bogs line the foothills of the Transantarctic Mountains not far from the South Pole—the last members of a venerable line of once-majestic forests that had existed since long before the age of the dinosaurs.

What we've glossed over in our journey back to this ancient present: the entire evolutionary history of *Homo sapiens*, three Yellowstone super-eruptions, thousands of megafloods, the last of the giant terror birds, a mass extinction of whales, and the glacial creation and destruction of innumerable islands and moraines. As we make our way backwards in time to the Pliocene, the glaciations get briefer, and the ice sheets themselves become thinner and more temperamental. About 2.6 million years ago they all but disappear in North America, as CO_2 levels continue their slow climb.

When we arrive in the middle of the Pliocene, just over 3 million years ago, CO_2 levels are high enough that we've escaped the cycle of ice ages and warm interglacials altogether. Lucy the *Australopithecus* roams a heavily forested East Africa. We are now outside the evolutionary envelope of our modern world, sculpted as it was by the temperamental northern ice sheets and deep freezes of the Pleistocene. But as to atmospheric carbon dioxide, 3 million years is how far back we have to go to arrive at an analogue for 2021.

Despite the similarities between our world and that of the Pliocene, the differences are notable. In the Canadian High Arctic—where today tundra spreads to the horizon—evergreen forests come right to the edge of an ice-free Arctic Ocean. Though the world as a whole is only a few degrees warmer, the Arctic, as always, gets the brunt of the extra heat. This is called "polar amplification," and it's why maps of modern warming are crowned by a disturbing fog of maroon. Models struggle to reproduce the extreme level of warming in the Pliocene Arctic. It's a full 10 to 15 degrees Celsius warmer in the long twilight of northern Canada, and the pine and birch woodlands of these Arctic shores are filled with gigantic forest-dwelling camels. Occasionally this boreal world erupts in wildfire, a phenomenon echoed by the blazes that today sweep ever farther north. Elsewhere, West Antarctica's ice sheet may have disappeared entirely, and Greenland's, if it exists at all, is shriveled and pathetic.

A common projection for our own warming world is that, while the wet places will get wetter, the dry places will get drier. But the Pliocene seems to defy this saw for reasons not yet fully understood. It's a strangely wet world, especially the subtropics, where—in the Sahara, the Outback, the Atacama, the American Southwest, and Namibia—lakes, savannas, and woodlands replace deserts. This ancient wetness might come down to inadequacies in how we model clouds, which are under no obligation to behave in physical reality as they do in simplified lines of computer code. Hurricanes were almost certainly more consistently punishing 3 million years ago, just as our storms of the future will be. And a more sluggish circulation of the atmosphere might have lulled the trade winds, turning El Niño into "El Padre." Perhaps this is what brought rains—and lakes—to the Mojave at this time.

Our modern coastlines would have been so far underwater that you'd have to take great pains to avoid getting the bends if you tried scuba diving down to them. Today, traveling east through Virginia, or North or South Carolina, or Georgia, midway through your drive you'll pass over a gentle 100-foot drop. This is the Orangeburg Scarp, a bluff—hundreds of miles long—that divides the broad, flat coastal plain of the American Southeast. It comprises the eroded and smoothed-out rumors of once-magnificent sea cliffs. Here, waves of the Pliocene high seas chewed away at the middle of the Carolinas—an East Coast Big Sur. This ancient shoreline is visible from space by the change in soil color that divides the states, and is visible on much closer inspection as well: To the east of this strange drop-off, giant megalodon-shark teeth and whale bones litter the Carolina Low Country. Though warped over the ages by the secret workings of the mantle far below, these subtle banks 90 miles inland nevertheless mark the highest shoreline of the Pliocene, when the seas were dozens of feet higher than they are today. But even within this warm Pliocene period, the sea level leaped and fell by as much as 60 feet every 20,000 years, to the rhythm of the Earth's sway in space. This is because, under this higher-CO_2 regime, the unstable ice sheet in Antarctica took on the volatile temperament that, 1 million years later, would come to characterize North America's ice sheet, toying with the ancient coastline as if it were a marionette.

So this is the Pliocene, the world of the distant present. While today's projections of future warming tend to end in 2100, the Pliocene illuminates just what sort of long-term changes might inevitably be set in motion by the atmosphere we've already engineered. As the great ice sheets melt, the permafrost awakens, and darker forested land encroaches on the world's tundra, positive feedbacks may eventually launch our planet into a different state altogether, one that might resemble this bygone world. Nevertheless, human civilization is unlikely to keep atmospheric CO_2 at a Pliocene level—so more ancient and extreme analogues must be retrieved.

We're now deeper in the past, and the planet appears truly exotic. The Amazon is running backwards, and gathers in great pools at the foot of the Andes. A seaway stretches from Western Europe to Kazakhstan and spills into the Indian Ocean. California's Central Valley is open ocean.

What today is the northwestern U.S. is especially unrecognizable. Today the airy, columnated canyons of the Columbia River in Oregon swarm with tiny kiteboarders zipping through gorges of basalt. But 16 million years ago, this was a black, unbreathable place, flowing with rivers of incandescent rock. The Columbia River basalts—old lava flows that spread across Washington, Oregon, and Idaho, in some places more than two miles thick—were the creation of a class of extremely rare and world-changing volcanic eruptions known as large igneous provinces, or LIPs.

Some LIPs in Earth's history span millions of square miles, erupt for millions of years, inject tens of thousands of gigatons of CO_2 into the air, and are responsible for most of the worst mass extinctions in the history of the planet. They live up to their name—they are large. But these mid-Miocene eruptions were still rather small as far as LIPs go, and so the planet was spared mass death. Nevertheless, the billowing volcanoes raised atmospheric CO_2 up to about 500 ppm, a level that today represents something close to the most ambitious and optimistic scenario possible for limiting our future carbon emissions.

In the Miocene, this volcanic CO_2 warmed up the world to at least 4 degrees Celsius and perhaps as much as 8 degrees above modern temperatures. As a result, there were turtles and parrots in Siberia. Canada's Devon Island, in the high Arctic, is today a desolate wasteland, the largest uninhabited island in the world—and one used by NASA to simulate life on Mars. In the Miocene, its flora resembled Lower Michigan's.

The sweeping grasslands distinctive to our cooler, drier, low-CO_2 world had yet to take over the planet, and so forests were everywhere—in the middle of Australia and Central Asia and Patagonia. All of this vegetation was one of the reasons it was so warm. Forests and shrubs made this planet darker than our own world—one still painted pallid hues in many places by bare land and ice—and allowed it to absorb more heat. This change in the planet's color is just one of the many long-term feedback loops awaiting us after the ice melts. Long after our initial pulse of CO_2, they will make our future world warmer and more alien still.

As for fauna, we're now so distantly marooned in time from our own world that most of the creatures that inhabited this leafy planet range from the flatly unfamiliar to the uncannily so. There were big cats that weren't cats, and rhino-size "hell pigs" that weren't pigs. There were sloths that lived in the ocean and walruses that weren't related to today's walruses. Earth's largest-ever meat-eating land mammals, African juggernauts like Megistotherium and Simbakubwa, not closely related to any living mammals today, tore early elephants apart with bladed mouths.

And with CO_2 at 500 ppm, the sea level was about 150 feet higher than today. Approaching Antarctica in the middle Miocene by sea, the waters would be warmer than today, and virtually unvisited by ice. To get to the ice sheet, you'd have to hike far past lakes and forests of conifers that lined the coast. Trudging past the trees and finally over endless tundra, you would come at last to the edge of a much smaller ice sheet whose best days were still ahead of it. An axiom about this land-based Antarctic ice sheet in paleoclimatology is that it's incredibly stubborn. That is, once you have an ice sheet atop the heart of Antarctica, feedback loops kick in to make it exceedingly hard to get rid of. Barring true climatic madness, a land-based Antarctic ice sheet is essentially there to stay.

But in the middle Miocene this young Antarctic ice sheet seemed to have a temper. It might have been "surprisingly dynamic," as one paper cheerfully puts it. As CO_2 increased from just below today's levels up to about 500 ppm, Miocene Antarctica shed what today would amount to 30 to 80 percent of the modern ice sheet. In the Miocene, Antarctica seemed exquisitely tuned to small changes in atmospheric CO_2, in ways that we don't fully understand and that we're not incorporating into our models of the future. There will undoubtedly be surprises awaiting us in our high-CO_2 future, just as there were for life that existed in the Miocene. In fact, the Antarctic ice sheet may be more vulnerable today to rapid retreat and disintegration than at any time in its entire 34-million-year history.

In the 16 million years since this mid-Miocene heat, the volcanic hot spot responsible for the Columbia River basalts has wandered under Yellowstone. Today it powers a much tamer kind of volcano. It could cover a few states in a few inches of ash and disrupt global agriculture for years, but it couldn't launch the planet into a new climate for hundreds of thousands of years, or kill most life on the surface. Unfortunately, there is such a supervolcano active on Earth today: industrial civilization. With CO_2 likely to soar past 500 ppm from future emissions, even the sweat-soaked, Siberian-parrot-populated world of the middle Miocene might not tell us everything we need to know about our future climate. It's time to go back to a global greenhouse climate that ranks among the warmest climate regimes complex life has ever endured. In our final leap backwards, CO_2 at last reaches levels that humans might reproduce in the next 100 years or so. What follows is something like a worst-case scenario for future carbon emissions. But these worst-case projections have continued to prove stubbornly accurate in the 21st century so far, and they remain a possible path for our future.

We're now about to take our largest leap, by far, into the geologic past. We hurdle over 40 million years of history, past volcanic eruptions thousands of times bigger than that of Mount St. Helens, past an asteroid impact that punched out a gigantic crater where the Chesapeake Bay sits today. The Himalayas slump; India unhitches from Asia; and the further back we go, the higher the CO_2 level rises and the warmer the Earth gets. The Antarctic ice sheet, in its death throes, vanishes altogether, and the polar continent instead gives way to monkey puzzle trees and marsupials. We have arrived, finally at the end of our journey, in the greenhouse world of the early age of mammals.

Today the last dry land one steps on in Canada before setting out across the ice-choked seas for the North Pole is Ellesmere Island, at the top of the world. But once upon a time there was a rainforest here. We know this because tree stumps still erode out of the barren hillsides, and they're more than 50 million years old. They're all that's left of an ancient polar jungle now whipped by indifferent Arctic winds. But once upon a time, this island was a swampy cathedral of redwoods, whose canopy naves were filled with flying lemurs, giant salamanders, and hippolike beasts that pierced the waters. At this polar latitude, on some late-fall evening of the early Eocene, the sun tried and failed to lift itself from the horizon. A pink twilight reached deep into the jungle, but soon the sun would set entirely here for more than four months. In this unending Arctic dark, the stillness would be broken by the orphaned calls of tiny early primates, who hopped fearlessly over stilled alligators that would start moving again when the sun returned from beyond the horizon. In this unending night, tapirs hunted for mushrooms and munched on leaf litter that was left over from sunny days past and that in the far future would become coal.

Humans now threaten to undo the entire climate evolution of the Cenozoic era—and in only a few decades.

We have no modern analogue for a swampy rainforest teeming with reptiles that nevertheless endures months of Arctic twilight and polar night. But for each degree Celsius the planet warms, the atmosphere holds about 6 percent more water vapor, and given that global temperatures at the beginning of the age of mammals were roughly 13 degrees warmer than today, it's difficult to imagine how uncomfortable this planet would be for Ice Age creatures like ourselves. In fact, much of the planet would be rendered off-limits to us, far too hot and humid for human physiology.

Not only was this a sweltering age, but it was also one cruelly punctuated by some of the most profound and sudden CO_2-driven global-warming events in geologic history—on top of this already feverish baseline. Deep under the North Atlantic, the Eocene epoch kicked off in style 56 million years ago with massive sheets of magma that spread sideways through the crust, igniting vast, diffuse deposits of fossil fuels at the bottom of the ocean. This ignition of the underworld injected something like the carbon equivalent of all currently known fossil-fuel reserves into the seas and atmosphere in less than 20,000 years, warming the planet by another 5 to 9 degrees Celsius. Evidence abounds of violent storms and megafloods during this ancient spasm of climate change—episodic waves of torrential rains unlike any on Earth today. In some places, such storms would have been routine, separated by merciless droughts and long, brutal, cloudless heat waves. Seas near the equator may have been almost as hot as a Jacuzzi—too hot for most complex life. As for the rest of the planet, all of this excess CO_2 acidified the oceans, and the world's coral reefs collapsed. Ocean chemistry took 200,000 years to recover.

The most jarring thing about the early age of mammals, though, isn't merely the extreme heat. It's the testimony of the plants. In higher-CO_2 conditions, plants reduce the number of pores on their leaves, and fossil leaves from the jungles of the early Eocene have tellingly fewer pores than today's. By some estimates, CO_2 50 million years ago was about 600 ppm. Other proxies point to higher CO_2, just over 1,000 ppm, but even that amount has long bedeviled our computer models of climate change. For years, in fact, models have told us that to reproduce this feverish world, we'd need to ramp up CO_2 to more than 4,000 ppm.

This ancient planet is far more extreme than anything being predicted for the end of the century by the United Nations or anyone else. After all, the world that hosted the rainforests of Ellesmere Island was 13 degrees Celsius warmer than our own, while the current global ambition, enshrined in the Paris Agreement, is to limit warming to less than 2, or even 1.5, degrees. Part of what explains this glaring disparity is that most climate projections end at the end of the century.

Feedbacks that might get you to Eocene- or Miocene-level warmth play out over much longer timescales than a century. But the other, much scarier insight that Earth's history is very starkly telling us is that we have been missing something crucial in the models we use to predict the future.

Some of the models are starting to catch up. In 2019, one of the most computationally demanding climate models ever run, by researchers at the California Institute of Technology, simulated global temperatures suddenly leaping 12 degrees Celsius by the next century if atmospheric CO_2 reached 1,200 ppm—a very bad, but not impossible, emissions pathway. And later that year, scientists from the University of Michigan and the University of Arizona were similarly able to reproduce the warmth of the Eocene by using a more sophisticated model of how water behaves at the smallest scales.

The paleoclimatologist Jessica Tierney thinks the key may be the clouds. Today, the San Francisco fog reliably rolls in, stranding bridge towers high above the marine layer like birthday candles. These clouds are a mainstay of west coasts around the world, reflecting sunlight back to space from coastal California and Peru and Namibia. But under higher-CO_2 conditions and higher temperatures, water droplets in incipient clouds could get bigger and rain down faster. In the Eocene, this might have caused these clouds to fall apart and disappear—inviting more solar energy to reach, and warm, the oceans. That might be why the Eocene was so outrageously hot.

This sauna of our early mammalian ancestors represents something close to the worst possible scenario for future warming (although some studies claim that humans, under truly nihilistic emissions scenarios, could make the planet even warmer). The good news is the inertia of the Earth's climate system is such that we still have time to rapidly reverse course, heading off an encore of this world, or that of the Miocene, or even the Pliocene, in the coming decades. All it will require is instantaneously halting the super-eruption of CO_2 disgorged into the atmosphere that began with the Industrial Revolution.

We know how to do this, and we cannot underplay the urgency. The fact is that none of these ancient periods is actually an apt analogue for the future if things go wrong. It took millions of years to produce the climates of the Miocene or the Eocene, and the rate of change right now is almost unprecedented in the history of animal life.

Humans are currently injecting CO_2 into the air 10 times faster than even during the most extreme periods within the age of mammals. And you don't need the planet to get as hot as it was in the early Eocene to catastrophically acidify the oceans. Acidification is all about the rate of CO_2 emissions, and we are off the charts. Ocean acidification could reach the same level it did 56 million years ago by later this century, and then keep going.

When he coined the term *mass extinction* in a 1963 paper, "Crises in the History of Life," the American paleontologist Norman Newell posited that this was what happened when the environment changed faster than evolution could accommodate. Life has speed limits. And in fact, life today is still trying to catch up with the thaw-out of the last ice age, about 12,000 years ago. Meanwhile, our familiar seasons are growing ever more strange: Flycatchers arrive weeks after their caterpillar prey hatches; orchids bloom when there are no bees willing to pollinate them. The early melting of sea ice has driven polar bears ashore, shifting their diet from seals to goose eggs. And that's after just 1 degree of warming.

Subtropical life may have been happy in a warmer Eocene Arctic, but there's no reason to think such an intimately adapted ecosystem, evolved on a greenhouse planet over millions of years, could be reestablished in a few centuries or millennia. Drown the Florida Everglades, and its crocodilians wouldn't have an easy time moving north into their old Miocene stomping grounds in New Jersey, much less migrating all the way to the unspoiled Arctic bayous if humans re-create the world of the Eocene. They will run into the levees and fortifications of drowning Florida exurbs. We are imposing a rate of change on the planet that has almost never happened before in geologic history, while largely preventing life on Earth from adjusting to that change.

Taking in the whole sweep of Earth's history, now we see how unnatural, nightmarish, and profound our current experiment on the planet really is. A small population of our particular species of primate has, in only a few decades, unlocked a massive reservoir of old carbon slumbering in the Earth, gathering since the dawn of life, and set off on a global immolation of Earth's history to power the modern world. As a result, up to half of the tropical coral reefs on Earth have died, 10 trillion tons of ice have melted, the ocean has grown 30 percent more acidic, and global temperatures have spiked. If we keep going down this path for a geologic nanosecond longer, who knows what will happen? The next few fleeting moments are ours, but they will echo for hundreds of thousands, even millions, of years. This is one of the most important times to be alive in the history of life.

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