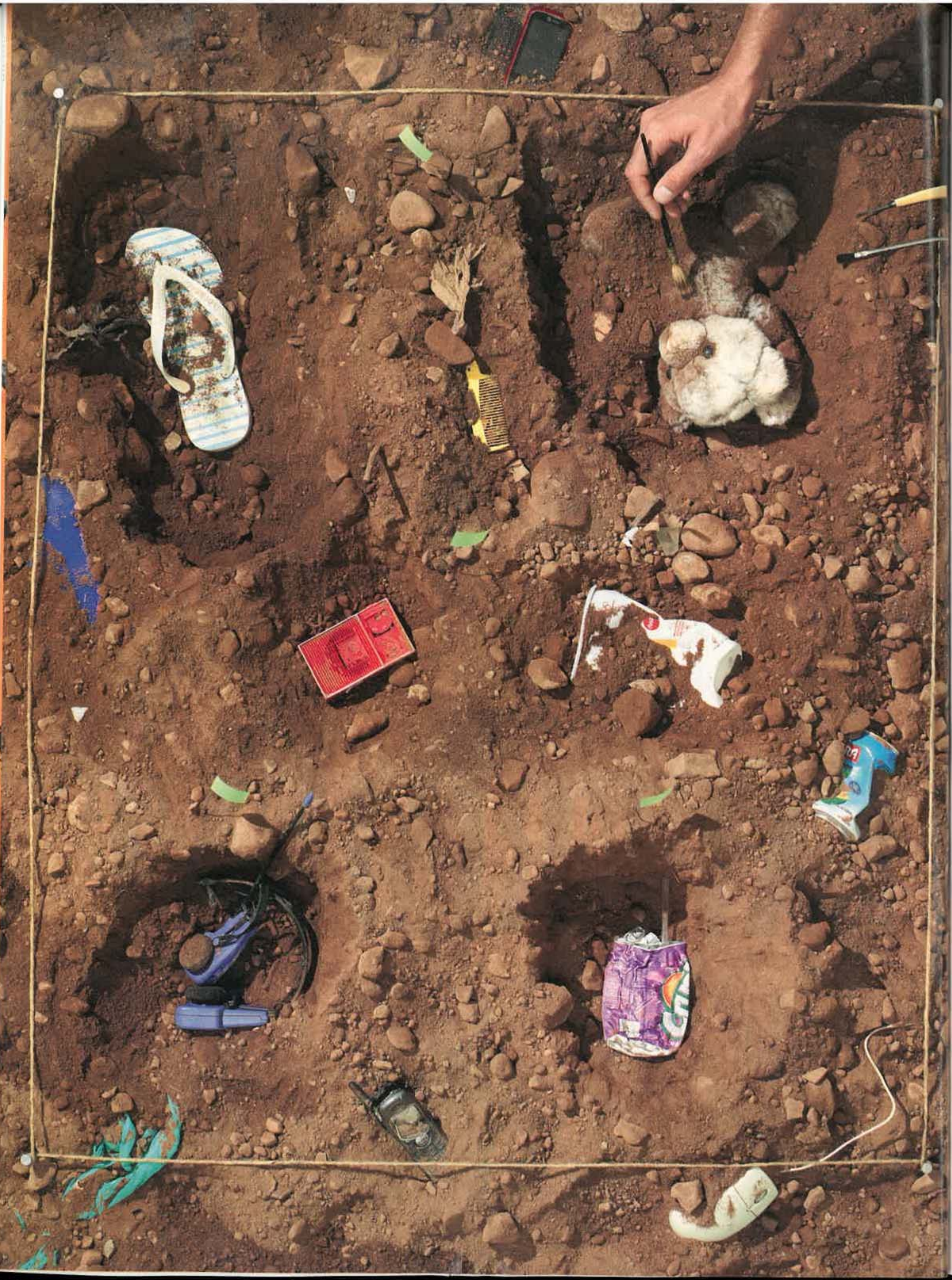

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WHAT MARK WILL WE LEAVE ON THE PLANET?

By Jan Zalasiewicz

A HISTORY IN LAYERS

Photograph by Andrew Myers

Jan Zalasiewicz is a professor of paleobiology at the University of Leicester in England and is chair of the Anthropocene Working Group of the International Commission on Stratigraphy. He has a particular fondness for graptolites—an extinct form of plankton.

IN BRIEF

Humans have altered the earth's systems, yet scientists are debating whether the changes will leave permanent signatures in geologic layers of rock, which define formal epochs and eras.

We have spread aluminum, plastics, concrete, carbon particulates (from burning fossil fuels), insecticides and radioactive particles (released by nuclear bombs) widely across the landscape and oceans—all evidence favoring the declaration of a new Anthropocene epoch.

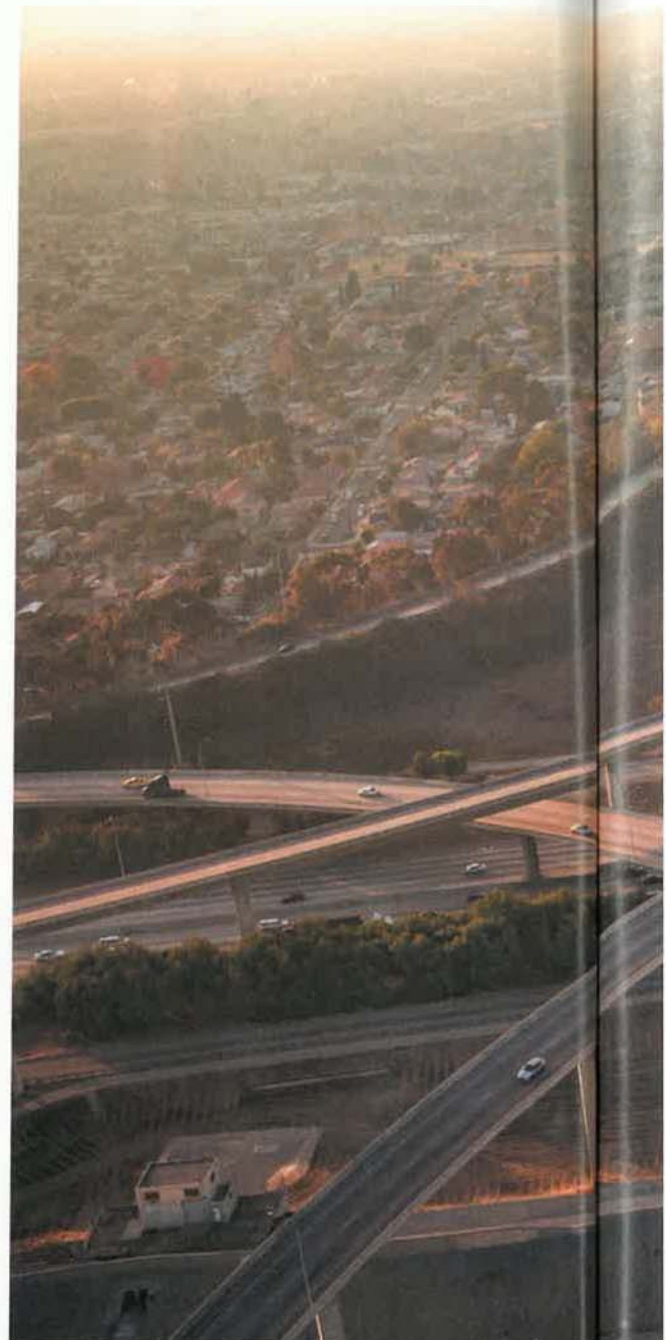
Questions remain about whether such an epoch would have begun thousands of years ago, when human impacts were first discernible, or may only begin at some future time, when the full impact of humans will have played out.

The idea was born in Mexico, in the year 2000. It was pure improvisation, by Paul Crutzen, one of the world's most respected scientists. The Dutch scholar was widely known for arguing that all-out atomic war would trigger a "nuclear winter" lethal to plant and animal life across the earth, and he had won a Nobel Prize for research into another global threat: human-caused destruction of the earth's ozone layer.

In Mexico he was listening to experts discuss evidence for changes in the global environment that had occurred throughout the Holocene, a distinct epoch that geologists say began 11,700 years ago and continues today. Growing visibly more frustrated, he burst out: "No! We are no longer in the Holocene. We are in"—he paused to think—"the Anthropocene!"

The room went silent. The term had apparently hit home. And it kept coming up, again and again, for the rest of the meeting. That year Crutzen co-wrote an article with Eugene Stoermer (since deceased), a specialist in microscopic algae called diatoms who had independently coined the term "Anthropocene" some years earlier. The evidence, the two men said in the article, was clear: industrialized humanity had changed the composition of the earth's atmosphere and oceans and had modified the landscape and biosphere—including diatom populations. We were living on a new human-driven earth, quite different from the old one. Spurred by Crutzen's prestige and vivid, persuasive writing, the concept spread rapidly among the thousands of scientists in the International Geosphere-Biosphere Program, which had sponsored the Mexico meeting. "The Anthropocene" began to appear in scientific papers around the world.

But was this really *geologic* change—change so profound that its signals are imprinted into geologic strata across the planet? Could humans really wreak change as dramatic as the transformations that started the Holocene 11,700 years ago, when extensive glaciers covering much of the earth were retreating, melting so much they raised sea level globally by 120 meters? Were human influences on the dirt beneath our feet as significant as when the Pleistocene epoch began, 2.6 million years ago, as the Ice Age tightened its grip? Could human effects only a few centuries old truly be measured alongside the great shifts of our planet's tumultuous geologic past, where time units are measured in millions—and even billions—of years?



The idea had appeared before. In the 19th and early 20th centuries scholars such as Italian cleric Antonio Stoppani and American naturalist Joseph LeConte floated terms such as Anthropozoic and Psychozoic, but geologists were dismissive, even scathing. How could human activity—no matter how impressive—compare with profound changes such as the creation and destruction of entire oceans and mountain ranges, massive volcanic eruptions and monstrous collisions by incoming meteorites? Against such a scale, human actions appeared fleeting and ephemeral.

There was another problem, too. Geologic terms such as Jurassic, Cretaceous, Pleistocene and Holocene are not just labels. They are formal names that are part

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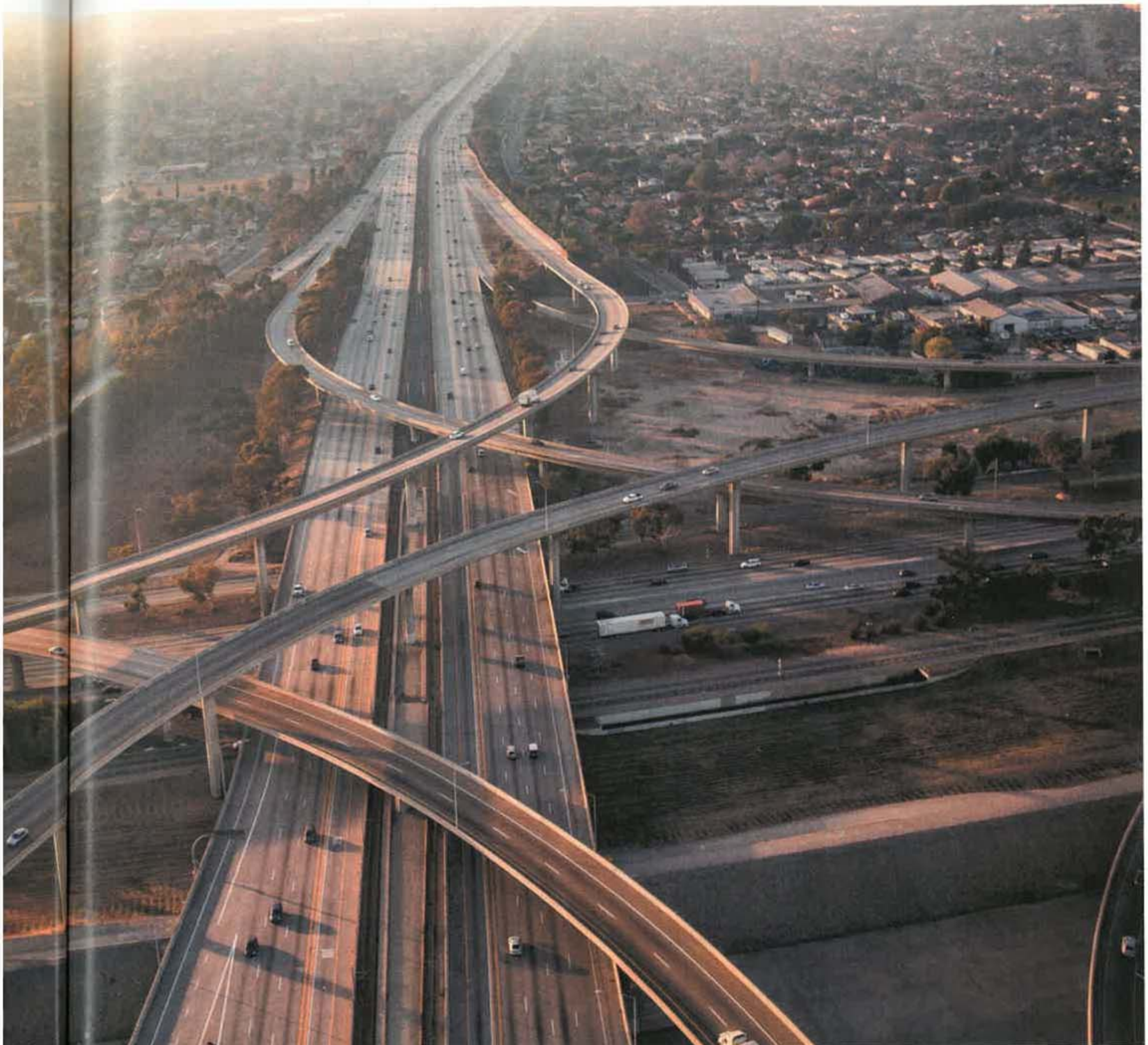

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of a complex geologic time scale that fundamentally characterizes how the earth evolved, thrived and struggled over 4.6 billion years. The names were accepted only after decades of evidence gathering and discussion by the International Commission on Stratigraphy. "Epochs" and the "eras" they belong to have specific technical meanings, and geologists take them seriously. Declaring a new epoch would imply that scientists believe humans were altering the course of the earth's evolution.

The Anthropocene had gone through none of the usual assessments. And esteemed as Crutzen is, he was an atmospheric chemist working on environmental stresses, not a geologist who was an expert in rock strata. Yet by 2008 members of the Stratigraphy Commission of the Geological Society of London realized that the term was increasingly being used in the literature as if it *were* a formal epoch. The society decided it had to confront the trend.

HUMANS are paving paradise, transforming the planet's strata and defining a new geologic epoch: the Anthropocene.

This cautious and conservative group meets in the old-world Council Room in London's Burlington House, complete with solemn portraits on the walls, where Victorian giants of the sciences such as Charles Darwin once walked. In this heavily traditional setting, the scientists began the geologic assessment of the Anthropocene. Perhaps to their own surprise, most of them agreed that the term "had merit" as a potentially formal unit of the proper geologic time scale and should be examined. Geologist Philip Gibbard, who also chaired the Interna-

MOUNTAINS of plastics in Jakarta and of concrete in New York City will persist long enough to permanently impregnate the earth's crust.

tional Commission on Stratigraphy's Subcommission on Quaternary Stratigraphy—which has power over the geological time scale—proposed a working group that has been exploring the question ever since.

To make a case, scientists must show that human impacts will leave a clear mark, fossilized in strata, that could be readily recognized tens or hundreds of millions of years from now by some geologist in the far future. The focus on strata is important. To a geologist, geologic strata *equal* geologic time. The key is a "time-rock" interval—a layer of strata that can be hammered, sampled or dug in (as for dinosaur bones) and that defines a new course of history. For the Anthropocene epoch to have such deep geologic meaning and to have any chance of being made formal, it must show its own time-rock unit. Is there enough evidence to pass muster? One could make a good case.

ROCKS AND 'OIDS

LET'S START WITH MINERALS, the fundamental components of rocks. Metals, for example, are almost always bound up in various oxides, carbonates and silicates (with rare exceptions such as gold). Humans have learned to separate metals out of these compounds, in huge quantities. We have manufactured more than 500 million metric tons of aluminum since World War II, enough to coat the entire U.S. in kitchen foil. As we scatter billions of cans, appliances, cigarette pack liners and other refuse across the landscape and into landfills, pure aluminum is becoming part of modern sediment layers.

The last great rise in mineral forms occurred about 2.5 billion years ago, when the earth's atmosphere became oxygenated. The event produced an array of oxides and hydroxides, including rust—which, incidentally, changed the color of the landscape from gray to red. But humans have now created another great rise by synthesizing many mineral compounds, such as tungsten carbide, common in tools and ballpoint pens. Perhaps the most striking inventions are "mineraloids" such as glasses and plastics. Before WWII plastics were limited to a few products such as shellac, Bakelite and rayon, but after the war they rocketed to the 300 million metric tons now made annually—roughly equivalent to the total human body mass. The qualities we find so useful in plastics—durability and resistance to decay—mean that they persist in the environment for many years.

The signature of plastic litter in the ground is strong enough, but it is even more geologically significant in the oceans. Because many sea creatures eat plastics, much of it ends up in the muds of the seafloor when the animals die—a first step to fossilization. Invisible to our eyes but more pervasive still are microplastics, such as the fibers detached from synthetic clothes. Even on remote ocean floors, far from land, researchers are finding thousands of fibers in every square meter of mud.

Human-made rocks are everywhere, too. For sheer bulk, concrete now reigns supreme; we have manufactured something like half a trillion metric tons to date. That is about a kilogram of concrete for every square meter of the earth's surface. Concrete forms the superstructures of our buildings, roads and dams, and broken-up fragments are now common in the turned-over ground underneath our towns and cities. It is already a signature rock of the Anthropocene, together with human-made bricks and ceramics. The enormous masses of the rocks we make impregnate the top part of the earth's crust, which we are also redistributing as big machines dig and plow soil to construct buildings and grow food. Humans now shift more sediment than natural forces such as rivers and wind do.

CHEMICAL FINGERPRINTS

IN THE PAST CENTURY or so, the burning of fossil fuels has largely powered the accelerated production and plane-

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tary deposition of new strata materials such as aluminum, plastic and concrete. The by-products of combustion are themselves so voluminous that they, too, leave a variety of chemical signals in sediments worldwide. The rise of carbon dioxide in the atmosphere since the industrial revolution began is about 100 times faster than the rate of rise when the glaciers retreated at the start of the Holocene. The emissions are captured and recorded in bubbles of air trapped in layer on layer of snow and ice frozen in the world's polar caps.

Combustion also produces smoke—incompletely burned particles that are tiny and inert. Falling to the ground worldwide, they form a geologically lasting smoke signal. The fires ignited by the meteorite impact that defines the boundary between the Cretaceous and Tertiary intervals left a similar trace in the rocks. The carbon from burned fossil fuels is also distinctly rich in the light carbon 12 isotope (^{12}C), which plants and animals readily absorb. As these life-forms die, they will be fossilized, leaving a permanent ^{12}C mark of the Anthropocene.

Widespread agriculture is casting its own chemical shadow. Humankind started farming about 10,000 years ago, but only since the early 1900s have farmers applied vast quantities of nitrogen fertilizer, extracted from the air by a technique known as the Haber-Bosch process, together with phosphorus dug from the ground. The enormous perturbations in soil, water and air leave clear chemical signatures. Lakes at high latitudes become polluted by these compounds, blown in by winds from distant farming regions. Fertilizer runoff from farm fields into streams and rivers and out to the sea overstimulates plankton production; as the huge blooms die and decay, they create "dead zones" that now suffocate seafloor life over hundreds of thousands of square kilometers every year. The devastated marine biology will tell its story as fossils in future strata.

Other chemical signals include persistent organic pollutants such as insecticides and toxic industrial chemicals such as dioxins, which now contaminate many sediments. Some of these may persist over geologic time scales, as did the long-chain carbon compounds produced by some ancient algae that paleontologists now use as tracers of climate tens of millions of years ago.

Tiny radioactive particles that spread around the globe after every nuclear bomb explosion are also detectable. Although only a couple of such bombs were dropped as part of war, various countries detonated more than 500 test bombs in the atmosphere between the mid-1940s and the late 1990s. The particles fell into soil, polar ice and seafloor sediment alike, and they were absorbed by animals and plants at the surface. This radioactive layer is one of the most abrupt Anthropocene signatures.

FOSSIL TRANSITIONS

WE HUMANS have obviously left our mark on the earth's biological landscape as well. In particular, our species—a very minor player amid the planet's biota even a few thousand years ago—is now the dominant predator on land and sea. We appropriate roughly a quarter of the earth's total biological production for our needs. As a result, we make up about a third of the mass of all land vertebrates (based simply on body weight), and the handful of animal species we have engineered to become our food make up most of the other two thirds. Wild animals, pushed to the margins, constitute 5 percent or less. In colonizing so much of the planet's land, we have comprehensively reshuffled what is left of wildlife, too, purposely or accidentally transporting animals and plants across the

TOP SCIENTISTS PREDICT OUR FUTURE

DOES HUMANITY HAVE A FUTURE BEYOND EARTH?

"I think it's a dangerous delusion to envisage mass emigration from Earth. There's nowhere else in the solar system that's as comfortable as even the top of Everest or the South Pole. We must address the world's problems here. Nevertheless, I'd guess that by the next century, there will be groups of privately funded adventurers living on Mars and thereafter perhaps elsewhere in the solar system.

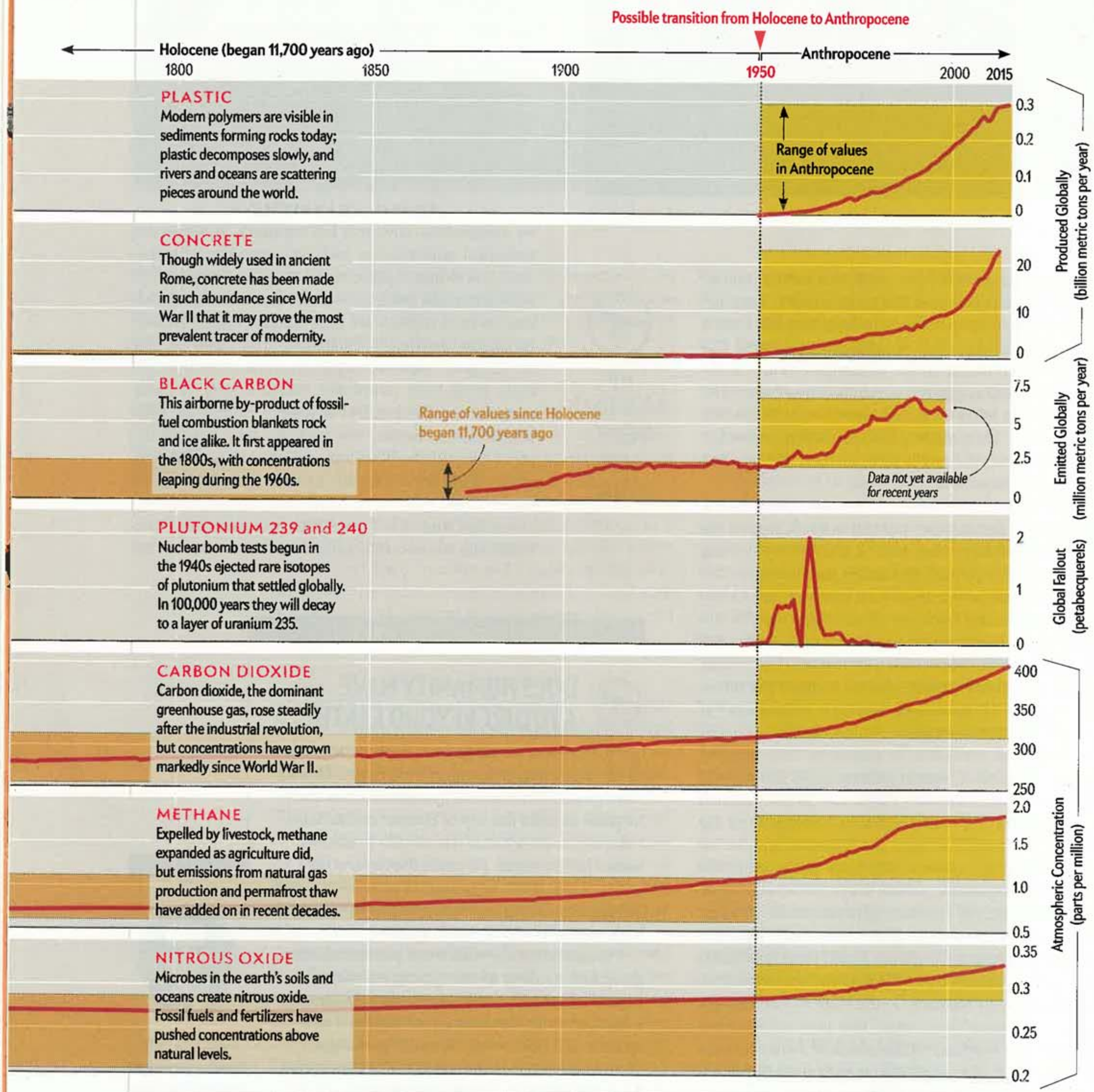
We should surely wish these pioneer settlers good luck in using all the cyborg techniques and biotech to adapt to alien environments. Within a few centuries they will have become a new species: the posthuman era will have begun. Travel beyond the solar system is an enterprise for posthumans—organic or inorganic.

MARTIN REES
British cosmologist and astrophysicist

Portrait by Kyle Hilton

When Did the Anthropocene Begin?

The detritus of modern humanity is so pervasive that our "techno-fossils"—such as plastic and concrete—will permeate the rock that is forming today. Mounting evidence collected by scientists supports the idea that human activity has pushed the planet into a new geologic epoch: the Anthropocene. They say the epoch will prove distinct from the Holocene, which began when glaciers retreated 11,700 years ago—and that 1950 may be the logical threshold between the two. Markers of the Anthropocene (*shown below*) have spread across the globe, says Colin Waters of the British Geological Survey. "We've in effect become a new geologic force." —*Katie Peek*



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Graphic by Katie Peek

globe, homogenizing biology worldwide. We are also killing so many species that in another century or two the planet's biodiversity could take as catastrophic a hit as the one that happened when the dinosaurs disappeared. These transformations will show up in the distant future as a switch from one assemblage of fossils to another.

Humans have meanwhile taken the manufacture of "trace fossils"—such as footprints by dinosaurs and burrows by sea worms—to completely new levels. Our mines and boreholes penetrate several kilometers into the ground, so deep that these traces permanently scar the planet. The towns and cityscapes that have made over the earth's surface are also mirrored in subsurface foundations, pipelines and subway systems.

PERMANENT OR FLEETING?

ALL IN ALL, we humans have left a formidable catalog of new geologic signatures. Will these effects *permanently* reconfigure the earth's strata and future history, defining a formal new epoch? Or, with humans gone, will the earth system spring back to normal, eroding our constructions into dust, like the fate of the mighty Ozymandias empire in Percy Bysshe Shelley's poem of the same name? It is still early days.

Luckily, four billion years of strata have left us a few lessons. Where the earth's crust is rising, such as on growing mountain ranges, surface structures are indeed eroded and washed away as sedimentary particles into some far-off sea. Where the crust is subsiding—as below many of the world's major deltas—the strata piling up can preserve even seemingly ephemeral traces, such as leaves, twigs and footprints. Therefore, San Francisco, pushed up by tectonic forces, seems destined to be weathered away. Sinking New Orleans, Shanghai and Amsterdam, however, will leave ample traces of their massive, complex structures, together with aluminum, plastic, ceramics—and skeletons with metal-filled teeth and artificial hips. When these strata are ultimately pushed up high by tectonic forces, millions of years from now, the newly minted cliffs will reveal a distinctive Anthropocene layer.

The permanence of fossils, and of long-term consequences of our actions, figures in the answer, too. The meteorite strike that ended the Cretaceous period was instantaneous; the immediate shock wave was over in hours. But its effects reshaped biology for millions of years, and the reverberations are still with us today. Without that meteorite we might not be here now; dinosaurs might still be ruling the earth.

Humanity's impact, swift though not that sudden, could likewise change the planet in ways that will be felt long after we disappear. Many trends are accelerating, and some—species extinction, climate change and sea-level rise—are only in their early stages. Regardless of when the fossil-fuel era finally ends, its effects will diminish only slowly, over many millennia. (And human civilization, which developed in the environmentally stable Holocene, will have to adapt to an unstable, changing planet for many generations.)

We may exert a long-term influence in another way as well. Humanity is a much more complex, protean planetary force than a meteorite strike or glacial retreat. Our extraordinary geologic power is driven by our intelligence, our manipulative ability and our hypersocial interactions that pass on new knowledge. These traits have allowed us to develop the technology that now keeps us alive, and that itself is evolving at an accelerating rate, literally from year to year.

This emergent technosphere, as Duke University professor emeritus Peter Haff calls it, can be considered an outgrowth of the biosphere. It has its own dynamics, over which we have only partial control. It includes the possibility that a silicon-based intelligence could soon vie with our own. Among all the ongoing global changes that will determine the geologic future of the earth, the technosphere is the wild card. It could produce a revised Anthropocene planetary state—only humans may no longer be calling the shots. For now scientists can decide only how to characterize the present. Should an earth that is rapidly, profoundly and permanently being transformed by humans be formally recognized in a new epoch in the geologic timescale?

For the geologists who would make the determination, the jury is still out. Important decisions need be made. When would the Anthropocene have begun, for instance? Suggestions have ranged from thousands of years ago, when human impacts first became discernible, to far into the future, once our impacts are fully expressed. For practical purposes, the most suitable boundary seems to be the extraordinary "great acceleration" of population, energy use and industrialization begun in the mid-1900s. Strata after that time are marked by strong rises in concrete, plastics, plutonium and the remains of a transformed biology.

Geologists are searching for a suitable "golden spike"—a carefully selected reference that serves as a global marker for a new epoch. Would that be provided by the radioactive nuclei or carbon particles trapped in the snow and ice layers of Greenland and Antarctica, in sediment layers in far-flung lakes and fjords, and on undisturbed seafloors? Or might it be some other indicator, a telltale change in living chemistry preserved within tree rings and annual coral growth bands? The hunt is on. ■

MORE TO EXPLORE

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