ANNALS OF EXTINCTION PART TWO

THE LOST WORLD

Fossils of the future.

BY ELIZABETH KOLBERT

Graptolites indicate a major die-off. What will the fossils of our own day reveal?

COURTESY JAN A. ZALASIEWICZ

The Geological Society of London, known to its members as the Geol Soc (pronounced "gee-ahl sock"), was founded in 1807, over dinner in a Covent Garden tavern. Geology was at that point a brand-new science, a circumstance reflected in the society's goals, which were to stimulate "zeal" for the discipline and to induce participants "to adopt one nomenclature." There followed long, often spirited debates on matters such as where to fix the borders of the Devonian period. "Though I don't much care for geology," one visitor to the society's early meetings noted, "I do like to see the fellows fight."

The Geol Soc is now headquartered in a stone mansion not far from Piccadilly Circus. On the outside, the style of the mansion is Palladian; inside, it leans more toward mid-century public library. Much of the place is wrapped in plastic, owing to a construction project that never quite seems to reach completion. Near the reception desk, behind a green velvet curtain, hangs a copy of the first geological map of Britain, which was published in 1815 by William Smith. (Smith's British biographer has called the map "one of the classics of English science"; his American counterpart has pronounced it "the map that changed the world.") At the top of the stairs, there's a reading room with a brass chandelier, a few armchairs, some scuffed tables, and a broken coffee machine.

On a sunny morning not long ago, Jan Zalasiewicz, a stratigrapher and longtime society member, was sitting in the reading room, wishing the coffee machine were functional so that he could make a cup of tea. Zalasiewicz is a slight, almost elfin man with shaggy graying hair and narrow blue eyes. He had come down to London that morning from his home, in Nottinghamshire, to give a visitor a tour. His perspective on the Geol Soc, and on the city more generally, was, he had to admit, idiosyncratic.

"This building has never been considered as a rock before," he observed. "But it is just as much made of geology as anything you would find out in the field.

"Clearly, very few of these objects will survive Pompeii style," he went on, gesturing, with a faraway look in his eyes, toward the chairs, the tables, the magazine racks, and the coffee machine. "But they won't simply disappear. They'll break down into rubble, and the rubble will be washed away. But even the rubble that's been washed away will have its own character, its own signal." He swivelled to take in the windows (mostly silica) and the panelling (made of wood). "Potentially, everything here is fossilizable," he said.

Walter White-like, Zalasiewicz leads a double life. By day, he's an expert on a group of ancient marine organisms known as graptolites. Zalasiewicz deeply admires graptolites, which thrived and diversified in the early Paleozoic, some five hundred million years ago, only to be very nearly wiped out in a catastrophic extinction event. Present him with a fossilized graptolite and he can tell you at a glance which biozone of the Silurian period it belongs to.

In his off-hours, Zalasiewicz is a provocateur, or, to be more British about it, "a scientific hooligan." He has more or less invented a new discipline, which might be called the stratigraphy of the future. It is based on a simple, if disturbing, premise: humans are so radically refashioning the planet—levelling so many forests, eliminating so many creatures that once occupied those forests, transporting so many other creatures around the globe, and burning through such vast quantities of fossil fuels to keep the whole enterprise going—that we may well end up producing a catastrophe comparable in scale to the one that laid waste to the graptolites. Already, Zalasiewicz is convinced, the geology of the planet has been permanently altered. The signal that will be left behind by our cities, our carbon emissions, and our potentially fossilizable detritus is strong enough, he maintains, that even a moderately competent stratigrapher, at a distance of a hundred million years or so, should be able to tell that something extraordinary happened in what to us represents the present. "We have already left a record that is now indelible," he has written.

In recognition of the ways that, collectively, we are all world-changers, Zalasiewicz believes that an adjustment in nomenclature is called for. Officially, our epoch is the Holocene, but Zalasiewicz believes it would probably be more accurate to say that we have entered the Anthropocene. He is trying to persuade his colleagues to formally consider this new term. He hopes to bring the matter to a vote of the International Commission on Stratigraphy in 2016. If he has his way, every geology textbook in the world will instantly become obsolete.

The path led up a hill, across a stream, back across the stream, and past the carcass of a sheep, which looked deflated, like a lost balloon. The hill was bright green, but treeless; generations of the sheep's relatives had kept anything from growing much above muzzle height. As far as I was concerned, it was raining. But in the Southern Uplands of Scotland, I was told, this counted only as a light drizzle, or smirr.

Zalasiewicz and I and two of his colleagues from the British Geological Survey had driven for more than five hours to get to the Uplands from the Survey's headquarters, near Nottingham. We were hiking to a spot called Dob's Linn, where, according to an old ballad, the Devil himself was pushed over a precipice by a pious shepherd named Dob. By the time we reached the cliff, the smirr seemed to be smirring harder. There was a view over a waterfall, which crashed down into a narrow valley. A few yards farther up the path loomed a jagged outcropping of rock. It was striped vertically, like a referee's jersey, in bands of light and dark. Zalasiewicz set his rucksack down on the soggy ground and adjusted his red rain jacket. He pointed to one of the dark-colored stripes. "Bad things happened in here," he told me.

Much as Civil War buffs visit Gettysburg, stratigraphers are drawn to Dob's Linn. It's one of those rare places where, owing to an accident of plate tectonics, a major turning point in life's history is visible right on the surface of the earth. In this case, the event is the end-Ordovician extinction, which occurred some four hundred and forty million years ago. In addition to nearly knocking out the graptolites, it killed off something like eighty per cent of the planet's species. ("Had the list of survivors been one jot different," Richard Fortey, a British paleontologist and a recent president of the Geol Soc, has observed, "then so would the world today.") Not coincidentally, Dob's Linn is also a great place to find graptolites.

To the naked eye, graptolite fossils look a bit like scratches and a bit like hieroglyphics. ("Graptolite" comes from the Greek, meaning "written rock"; the term was coined by Linnaeus, who dismissed graptolites as mineral encrustations trying to pass themselves off as the remnants of animals.) Viewed through a hand lens, they often prove to have lovely, evocative shapes; one species suggests a feather, another a lyre, a third the frond of a fern. Graptolites were colonial animals. Each one, known as a zooid, built itself a tiny, tubular shelter, known as a theca, that was attached to its neighbor's, like a row house. A single graptolite fossil thus represents a whole community, which drifted or, more probably, swam along as a single entity, feeding off even smaller plankton. Zalasiewicz lent me a hammer, and one of the graptolites I hacked out of the rock face had been preserved with peculiar clarity. It was shaped like a set of false eyelashes, but very small, as if for a Barbie. Zalasiewicz told me—doubtless exaggerating—that I had found a "museum-quality specimen." I pocketed it.

Graptolites had a habit—endearing from a stratigrapher's point of view—of speciating, spreading out, and dying off, all in relatively short order. Zalasiewicz likened them to Natasha, the tender heroine of "War and Peace." They were, he told me, "delicate, nervous, and very

"You can't compete with a retired pharmacist."

sensitive to things around them." This makes them useful "index fossils"—successive species can be used to identify successive layers of rock.

Once Zalasiewicz showed me what to look for at Dob's Linn, I, too, could see that "bad things" happened here. The dark stripes were shale; in them, graptolites were plentiful and varied. This indicated that there was nothing alive to consume the animals once they'd died and sunk to the seafloor. Soon, I'd collected so many that the pockets of my jacket were sagging. Many of the fossils were variations on the letter "V," with two arms branching away from a central node. Some looked like zippers, others like wishbones. Still others had arms growing off their arms, like tiny trees.

The lighter stone—also shale—was barren, with barely a graptolite to be found in it. Paradoxically, this was a sign of a healthy ocean floor, with lots of scavengers living in the muck. The transition from one state to another—from gray stone to black, from no graptolites to many—appears to have occurred suddenly and, according to Zalasiewicz, *did* occur suddenly. "The change here from gray to black marks a tipping point, if you like, from a habitable seafloor to an uninhabitable one," Zalasiewicz said. "And one might have seen that in the span of a human lifetime." He described this transition as "Cuvierian."

Zalasiewicz's colleagues from the British Geological Survey, Dan Condon and Ian Millar, had come to Dob's Linn to collect samples from the various stripes. (Zalasiewicz also worked for many years at the B.G.S.; he now teaches at the University of Leicester.) The samples, they hoped, would contain tiny crystals of zircon, which, after some complicated chemical manipulations, would allow them to date the layers of rock quite precisely. Millar, who grew up in Scotland, at first claimed to be undaunted by the smirr. But after a while even he admitted that it was pouring. Rivulets of mud were cascading down the face of the outcropping, compromising the samples. It was decided that we would have to come back the following day. The geologists packed up their gear and we squished back down the trail to the car. Zalasiewicz had made reservations at a bed-and-breakfast in the nearby town of Moffat. The town's attractions, I had read, included Britain's narrowest hotel and a bronze sheep.

The idea that the world can change suddenly and drastically—"in the span of a human lifetime"—is very old and, at the same time, very new. To the early members of the Geol Soc, the role of catastrophe in the earth's history was self-evident. These men—and they were, of course, all men—had read the great nineteenth-century French naturalist Georges Cuvier, who interpreted the fossil record as a chronicle of recurring tragedy. (When the Napoleonic Wars ended, in 1815, Cuvier was made an honorary Geol Soc member.)

"Life on earth has often been disturbed by terrible events," Cuvier wrote. "Living organisms without number have been the victims of these catastrophes."

Cuvier's view of life was challenged by Charles Lyell, another of the nineteenth century's most influential naturalists. According to Lyell, who served as the Geol Soc's fourteenth president and also as its twenty-first, the earth was capable of changing only very gradually. The way to understand the distant past was to look at the present. Since no one had ever seen the kind of cataclysm that Cuvier invoked, it was unscientific, or, to use Lyell's term, "unphilosophical," to imagine that such events took place. If it appeared from the fossil record that the world had changed abruptly, Lyell maintained, this just went to show how little the record was to be trusted.

Among the early converts to Lyell's view was Charles Darwin. In "On the Origin of Species," Darwin acknowledged that there were points in the earth's history when it appeared that "whole families or orders" had suddenly been exterminated. But, like Lyell, he took this as evidence that "wide intervals of time" were unaccounted for. Had the evidence of these intervals not been lost, it would have shown "much slow extermination." He wrote, "So profound is our ignorance, and so high our presumption, that we marvel when we hear of the extinction of an organic being; and as we do not see the cause, we invoke cataclysms to desolate the world!"

Such was Lyell and Darwin's influence that for more than a century, even as it became increasingly clear that "whole families or orders" had indeed at various points suddenly been eliminated, geologists eschewed any account of these episodes that might be construed as Cuvierian. This reluctance extended into the nineteen-eighties, when it was proposed that an asteroid plowing into the earth at the end of the Cretaceous period, sixty-five million years ago, was what had done in the dinosaurs, along with the plesiosaurs, the mosasaurs, the pterosaurs, the ammonites, most birds, and a significant proportion of mammals. The impact hypothesis was resisted until the nineteen-nineties, when the existence of a huge impact crater formed precisely at the end of the Cretaceous was confirmed. The crater lies off the Yucatán Peninsula, buried under half a mile of newer sediment.

While the discovery of the impact crater didn't exactly invalidate Lyell and Darwin's model, it revealed their dismissal of catastrophe to have been itself "unphilosophical." Life on earth *has* been "disturbed by terrible events," and "living organisms without number" have been their victims. What is sometimes called "neocatastrophism," but is mostly now just considered mainstream geology, holds that the world changes only very slowly, except when it doesn't.

As best as can be determined, the rate of change today is as fast as it's been at any time since the asteroid impact. This is why Zalasiewicz believes that the stratigraphers of the future should have a relatively easy time of it, even though who or what was responsible for the sudden alteration of the planet may not immediately be clear. At one point, he mused, "It may take them a little while to sort out whether we were the drivers of this, or if the cats or the dogs or the sheep were."

After everyone had changed into dry clothes, we met in the sitting room of the B. and B. for tea. Zalasiewicz had brought along several papers he had recently published on graptolites. Settling back in their chairs, Condon and Millar rolled their eyes. Zalasiewicz ignored them, patiently explaining to me the import of his latest monograph, "Graptolites in British Stratigraphy," which ran to sixty-six pages and included illustrations of more than six hundred and fifty species. In the monograph, the effects of the extinction event showed up more systematically, if also less vividly, than on the rain-slicked hillside. Until the end of the Ordovician, V-shaped graptolites were common. These included species like the *Dicranograptus ziczac*, whose tiny cups were arranged along arms that curled away and then toward each other, like tusks; and *Amphigraptus divergens*, which was shaped like a bat in flight. Only a handful of graptolite species survived the end-Ordovician extinction, which, it's now believed, was caused by the sudden glaciation of the supercontinent Gondwana. (No one is entirely sure what caused this glaciation.) Eventually, the surviving graptolites diversified and repopulated the seas of the Silurian. But Silurian graptolites had a streamlined body plan, more like a stick than like a set of branches. The V shape had been lost, never to reappear. Here, writ very, very small, was the fate of the dinosaurs, the pterosaurs, and the ammonites—a once highly successful form now relegated to oblivion.

That evening, when everyone had had enough of tea and graptolites, we went out to the pub on the ground floor of Britain's narrowest hotel, which is twenty feet across. After a pint or two, the conversation turned to another one of Zalasiewicz's favorite subjects: giant rats. Zalasiewicz pointed out that rats have followed humans to just about every corner of the globe, and it is his professional opinion that one day they will take over the earth.

"Some number will probably stay rat-size and rat-shaped," he told me. "But others may well shrink or expand. Particularly if there's been epidemic extinction and ecospace opens up, rats may be best placed to take advantage of that. And we know that change in size can take place fairly quickly." I recalled once watching a rat drag a pizza crust along the tracks at an Upper West Side subway station. I imagined it waddling through a deserted tunnel, blown up to the size of a Doberman.

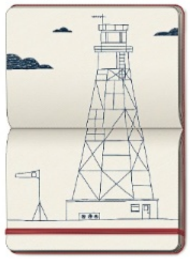
Though the connection might seem tenuous, Zalasiewicz's interest in giant rats represents a logical extension of his interest in graptolites. When he studies the Ordovician and the Silurian, he's trying to reconstruct the distant past on the basis of the fragmentary clues that remain—fossils, isotopes of carbon, layers of sedimentary rock. When he contemplates the future, he's trying to imagine what will remain of the present once the contemporary world has been reduced to fragments—fossils, isotopes of carbon, layers of sedimentary rock. One of the many aspects of the Anthropocene that he believes will leave a permanent mark is a reshuffling of the biosphere.

Often purposefully and just as often not, people have transported living things around the globe, importing the flora and fauna of Asia to the Americas and of the Americas to Europe and of Europe to Australia. Rats have consistently been in the vanguard of these movements, and they have left their bones scattered everywhere, including on islands so remote that humans never bothered to settle them. The Pacific rat, *Rattus exulans*, a native of Southeast Asia, travelled with Polynesian seafarers to, among many other places, Hawaii, Fiji, Tahiti, Tonga, Samoa, Easter Island, and New Zealand. Encountering few predators, stowaway *Rattus exulans* multiplied into what Richard Holdaway, a New Zealand paleontologist, has described as "a grey tide" that turned "everything edible into rat protein." (A recent study in the *Journal of Archaeological Science* concluded that it wasn't humans who deforested Easter Island; rather, it was the rats that came along for the ride and then bred unchecked. The native palms couldn't produce seeds fast enough to keep up with their appetite.)

When Europeans arrived in the Americas, and then continued west to the islands that the Polynesians had settled, they brought with them the even more adaptable Norway rat, *Rattus norvegicus*. In many places, Norway rats, which are actually from China, outcompeted the earlier rat invaders and ravaged whatever bird and reptile populations the Pacific rats had missed. Rats thus might be said to have created their own "ecospace," which their progeny seem well positioned to dominate. The descendants of today's rats, according to Zalasiewicz, will radiate out to fill the niches that *Rattus exulans* and *Rattus norvegicus* helped empty. He imagines the rats of the future evolving into new shapes and sizes—some "smaller than shrews," others as large as elephants.

"We might," he has written, in "The Earth After Us" (2008), "include among them—for curiosity's sake and to keep our options open—a species or two of large naked rodent, living in caves, shaping rocks as primitive tools and wearing the skins of other mammals that they have killed and eaten."

Meanwhile, whatever the future holds for rats, the extinction event that they are helping to bring about will leave its own mark. Many evolutionary lineages have recently come to an end; many, many more are likely soon to follow. Extinction rates today are hundreds of times higher—for some groups, such as amphibians and freshwater mollusks, perhaps thousands, or even tens of thousands, of times higher—than they've been since mammals took over the "ecospace" emptied by the dinosaurs. For reasons of geological history, the current extinction event is often referred to as the "sixth extinction." (By this accounting, the event recorded in the rocks at Dob's Linn is the first of the five major mass extinctions that have occurred since complex animal life evolved.) Whether the "sixth extinction" will turn out to be anywhere near as drastic as the first is impossible to know; nevertheless, it is likely to appear in the fossil record as a turning point. Climate change—itself a driver of extinction—will also leave behind geological traces, as will deforestation, industrial pollution, and monoculture farming.



Ultimately, most of our carbon emissions will end up in the oceans; this will dramatically alter the chemistry of the water, turning it more acidic. Ocean acidification is associated with some of the worst crises in biotic history, including what's known as the end-Permian extinction—the third of the so-called Big Five—which took place roughly two hundred and fifty million years ago and killed off something like ninety per cent of the species on the planet.

"Oh, ocean acidification," Zalasiewicz said when we returned to Dob's Linn the following day. "That's the big nasty one that's coming down."

In recent years, a number of names have been proposed for the new age that humans have ushered in. The noted conservation biologist Michael Soulé has suggested that, instead of the Cenozoic, we now live in the "Catastrophozoic" era. Michael Samways, an entomologist at South Africa's Stellenbosch University, has floated the term "Homogenocene." Daniel Pauly, a Canadian marine biologist, has recommended the "Myxocene," from the Greek word for "slime," and Andrew Revkin, an American journalist, has offered the "Anthrocene." (Most of these terms owe their origins, indirectly at least, to Lyell, who, back in the eighteen-thirties, coined the names Eocene, Miocene, and Pliocene.)

The word "Anthropocene" was put into circulation by Paul Crutzen, a Dutch chemist who, in 1995, shared a Nobel Prize for discovering the effects of ozone-depleting compounds. The importance of this discovery is difficult to overstate. Had it not been made—and had the chemicals continued to be widely used—the ozone "hole" that opens up every spring over Antarctica would have expanded until, eventually, it encircled the entire globe. One of Crutzen's fellow-Nobelists reportedly came home from his lab one night and said to his wife, "The work is going well, but it looks like the end of the world."

Crutzen once told me that the word "Anthropocene" came to him while he was in a meeting. The meeting's chairman kept referring to the Holocene, the "wholly recent" epoch, which began at the conclusion of the last ice age, eleven and a half thousand years ago. According to the International Commission on Stratigraphy, or I.C.S., which maintains the official geological time scale, the Holocene continues to this day.

" 'Let's stop it,' " Crutzen recalled blurting out. " 'We are no longer in the Holocene; we are in the Anthropocene.' Well, it was quiet in the room for a while." At the next coffee break, the Anthropocene was the main topic of conversation. Someone came up to Crutzen and suggested that he patent the term.

Crutzen wrote up his idea in a short essay, titled "Geology of Mankind," which ran in the journal *Nature*. "It seems appropriate to assign the term 'Anthropocene' to the present, in many ways human-dominated, geological epoch," he observed. Among the many geologic-scale changes people have effected, Crutzen cited the following:

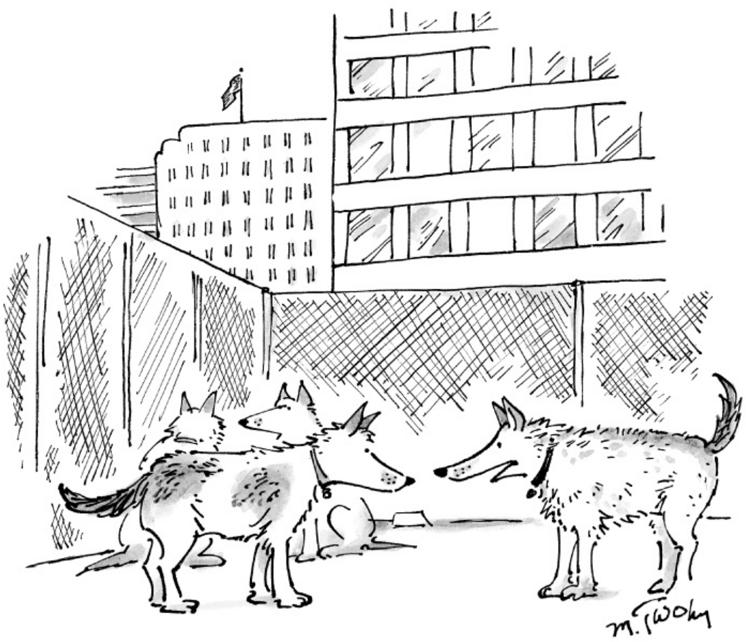
> Human activity has transformed between a third and a half of the land surface of the planet.
>
> Many of the world's major rivers have been dammed or diverted.
>
> Fertilizer plants produce more nitrogen than is fixed naturally by all terrestrial ecosystems.
>
> Humans use more than half of the world's readily accessible freshwater runoff.

Most significant, Crutzen noted, people have altered the composition of the atmosphere. Owing to a combination of fossil-fuel combustion and deforestation, the concentration of carbon dioxide in the air has risen by more than a third in the past two centuries, while the concentration of methane, an even more potent greenhouse gas, has more than doubled. Just a few more decades of emissions may bring atmospheric CO_2 to a level not seen since the mid-Miocene, fifteen million years ago. A few decades after that, it could easily reach a level not seen since the Eocene, some fifty million years ago. During the Eocene, palm trees flourished in the Antarctic, and alligators paddled around the British Isles.

"Because of these anthropogenic emissions," Crutzen wrote, the global climate is likely to "depart significantly from natural behavior for many millennia to come."

Crutzen published "Geology of Mankind" in 2002. Soon, the Anthropocene began migrating into other scientific journals. "Global Analysis of River Systems: From Earth System Controls to Anthropocene Syndromes" was the title of a 2003 article in the journal *Philosophical Transactions of the Royal Society B*. "Soils and Sediments in the Anthropocene," ran the headline of a piece, from 2004, in the *Journal of Soils and Sediments*.

Zalasiewicz noticed that most of those using the term were not trained in the fine points of stratigraphy, and he wondered how his colleagues felt about this. At the time, he was head of the Geol Soc's stratigraphy committee, and during a meeting one day he asked the members what they thought of the Anthropocene. Of the twenty-two



"Did you hear—we're being transferred from bomb-sniffing to trans fats."

stratigraphers present, twenty-one thought that the concept had merit.

"My response was it's a very interesting and powerful idea," Andy Gale, a professor at the University of Portsmouth, told me. "I felt it was worthwhile to pursue, because it's an important tool for making people think."

The group decided to approach the concept as a formal problem. Would the Anthropocene satisfy the stratigraphic criteria used for naming a new epoch? (To geologists, an epoch is a subdivision of a period, which, in turn, is a division of an era; the Holocene, for instance, is an epoch of the Quaternary, which is a period in the Cenozoic.) After a year's worth of study, the answer that the group arrived at was an unqualified yes. Among other things, the members observed in a paper summarizing their findings, the Anthropocene will be marked by a unique "biostratigraphic signal," a product of the current extinction event, on the one hand, and of the human propensity for redistributing life, on the other. This signal will be permanently inscribed, they wrote, "as future evolution will take place from surviving (and frequently anthropogenically relocated) stocks."

Or, as Zalasiewicz would have it, giant rats.

Just as in the early years of the Geol Soc, stratigraphers today spend a lot of time arguing about borders. A few years ago, after much heated discussion, members of the I.C.S. voted to move the start of the Pleistocene epoch from about 1.8 million to about 2.6 million years ago. This decision was part of a broader, and even fiercer, debate about whether to do away with the Quaternary, the period that spans both the Pleistocene and the Holocene, and fold it into the Neogene. (The elimination of the Quaternary was vigorously—and, ultimately, successfully—resisted by Quaternary stratigraphers.)

The debate over the Anthropocene's borders is complicated by the fact that the geology of the epoch is, at this point, almost entirely prospective. The way stratigraphers usually define boundaries—once they've stopped arguing about them—is by choosing a particularly fossil-rich sequence of rocks to serve as a reference. These reference sequences are colloquially known as "golden spikes"—technically, they're called Global Boundary Stratotype Sections and Points, or G.S.S.P.s—and they're scattered around the world (though a disproportionate number are in Europe). The striped rocks at Dob's Linn have been designated the golden spike for the start of the Silurian period. For the base of the Carboniferous, the golden spike is near the town of Cabrières, in southern France, and for the start of the Triassic it's in the hills of Meishan, China. (The Chinese have tried to turn this last golden spike into a tourist destination, with a manicured park and a statue of a tooth from a once common eel-like creature known as a conodont.)

Since the rocks of the Anthropocene don't yet exist, it's impossible to choose an exemplary sequence of them. To stratigraphers, then, a key, but also rather vexing, question is what could serve instead of the traditional golden spike. In 2009, the I.C.S. set up an Anthropocene Working Group to examine this and related issues; not surprisingly, Zalasiewicz was appointed chairman. At the time of our visit to London, he told me that he thought there were many possible ways that the start of the epoch could be designated. One would simply be to choose a date—1800, say, or 1950. This is how geological periods of the deep, pre-fossiliferous past are defined; what's known as the Neoproterozoic era, for example, is said to have begun precisely one billion years ago.

Another possibility would be to use nuclear fallout. The aboveground tests of the mid-twentieth century dispersed radioactive particles all around the globe. Some have half-lives of more than a thousand years; in a few cases, like uranium-236, the figure is in the tens of millions. To future geologists, the fallout will thus present a novel radioactive "spike" (assuming, that is, that the future does not hold a nuclear war). This sort of geochemical marker is used to define the end of the Cretaceous. The impact that occurred during the final seconds of the period left behind a thin layer of sediment containing anomalously high concentrations of the element iridium—the so-called "iridium spike."

Yet another possibility is to use the world's subway systems, an idea that also has precedent in deep time. Geologists refer to the outlines of burrows that creatures left behind in the sediments as "trace fossils." The start of the Cambrian period, some five hundred and forty million years ago, is defined as the point when the first complex burrows appear; these left impressions in the rocks which resemble scattered grains of rice. (No one is sure what the animals that made the burrows looked like, as their bodies have not been preserved.) London's subway system, the world's oldest, will leave behind an enormous set of trace fossils, as will New York's and Seoul's and Paris's and Dubai's.

"All the great world cities have underground systems now," Mark Williams, a stratigrapher who teaches at the University of Leicester and is a member of the Anthropocene Working Group, noted. "They're extensive, they're fairly permanent from a geological perspective, and they're a very, very good indicator of the complexity that's come to characterize the twentieth and twenty-first centuries."

Williams told me that the response to the idea of formalizing the Anthropocene had "generally been very positive." (Just in the past few months, three new academic journals focussing on the Anthropocene have been launched.) But, as is to be expected from a group that can sustain a decade-long disagreement about the status of the Quaternary, there's still plenty of dissent. Some critics argue that humans have been altering the planet for thousands of years already, so why get all worked up about it now?

"We can see that human interactions with the landscape are increasing," Philip Gibbard, a stratigrapher at Cambridge, told me. "No one disputes that. We build buildings. We build towns. We build roads. We drop plastic bags in the ocean. All that's absolutely true. But from a geological perspective—and I have to speak as a geologist, not as a generally interested person—I think what's happening now is just a logical continuation of something that began as human populations started to increase at the beginning of the Holocene.

"It is quite exciting to pursue this new idea," he added. "But I'm suspicious of it."

Other critics are skeptical of the idea for opposite reasons. They point out that human impacts on the planet are likely to become even more pronounced, and hence more stratigraphically significant, as time goes on. Thus, what's sometimes referred to in geological circles as the "event horizon" has not yet been reached.

For his part, Zalasiewicz is sympathetic to both lines of argument. Humans *have* been altering the planet for quite a while, though probably the impacts of the past were orders of magnitude more modest than they are today. And a few centuries from now the impacts of human activity may be orders of magnitude greater again. By the time people are through, Zalasiewicz told me, he wouldn't be surprised if the earth were rendered more or less unrecognizable. "One cannot exclude a P-T-type outcome," he observed, referring to the worst of the so-called Big Five, the end-Permian, or Permo-Triassic, extinction. In the meantime, though, he said, "we have to work with what we've got."

This past summer, I went with Zalasiewicz on another collecting trip, this one to Wales. Zalasiewicz has a special fondness for the country. He wrote his dissertation on the stratigraphy of northern Wales, and while finishing his research he drove around in a decommissioned postal van and lived in a camper that had been used as a chicken coop. He wanted to show me a spot near the town of Ponterwyd where he thought there should perhaps be another golden spike—in this case, marking the base of the Aeronian Stage of the Silurian. We set out from the town of Keyworth, in Nottinghamshire, where Zalasiewicz lives with his wife and teen-age son, and drove through the West Midlands. In its day, the West Midlands was the industrial heart of Britain. Now the industry is mostly gone, and people struggle to find work. "About as scary an advertisement for the Anthropocene as you can imagine" is how Zalasiewicz described the region.

When we arrived at Ponterwyd, smirr was falling, or, as the Welsh put it, piglaw. Again, there were lots of sheep and green, sheep-shorn hills, and rocks filled with fossils. Banging away at an outcropping, I soon found several graptolites. One, which Zalasiewicz identified as belonging to the species *Monograptus triangulatus*, looked like a tiny saw blade, with miniature triangular teeth. With characteristic tact, he told me that my specimen was "very lovely." I stuck it in my bag.

A few days later, I took the train back to London, and then the Tube out to Heathrow, where I was spending the night at an airport hotel. Thanks to all the graptolites I'd gathered, my suitcase was overweight, and I decided that I was going to have to deaccession some of them. I took what seemed to be the least impressive examples and headed out through the lobby, only to realize that there was nowhere to go. The hotel faced a ten-foot wall, which was made of plywood and covered with billboard-size sheets of plastic printed with photographs of trees. The photos kept repeating, so that walking along was like getting lost in a dark monoculture. Beyond the plywood wall, there was a parking lot, and beyond that an access road. I figured that the parking lot would have to do. By this point, I'd spent enough time with Zalasiewicz that the place appeared to me as a mosaic of human impacts. The lot was edged with a margin of dirt; this was filled with scraggly plants, many of them no doubt introduced species. Strewn among the weeds was the usual flotsam of travel: empty water bottles, crumpled candy wrappers, crushed soda cans, half-eaten packages of crisps. I recalled what Zalasiewicz had told me about aluminum, which is that until the late nineteenth century it did not exist on earth except in combination with other elements. So soda cans may provide yet another marker of our presence: the Dr Pepper spike.

It was a lovely evening. A half-moon hung in a purple sky crisscrossed by jet contrails. I took out my graptolites. Most I couldn't identify, but one, I thought, belonged to the species *Rhaphidograptus toernquisti*, which Zalasiewicz had described to me as among life's great success stories. *Rhaphidograptus toernquisti* managed to persist, unchanged, for some five million years. I placed my fossils in a little pile next to a discarded cigarette pack. Nearby, I noticed a plastic pouch with the word "Toxic" printed in block letters. The pouch was torn, and some ominously bright-yellow powder was leaking out of it. I tried to imagine a geologist in the year 100,000,000 A.D. stumbling onto the site. It was hard for me to picture what he (or it) would look like, but I got a certain satisfaction thinking about how puzzled he would be when he came upon my Silurian graptolites nestled amid the wreckage of the Anthropocene. ♦

(This is the second part of a two-part article.)