



There's no dispute that humans are leaving their mark on the planet, but geologists and other scientists are debating whether this imprint is distinctive and enduring enough to designate a new epoch: the Anthropocene

"Each time I see it, it's dramatic; the equivalent of listening to a particularly impressive bit of Mozart—like the opening of *Don Giovanni*, or the bit where Don gets dragged down to the pits," says geologist Jan Zalasiewicz of the University of Leicester in the United Kingdom.

The object of his awestruck tone seems unremarkable: a stripe of black rock abutting a pale gray section of cliff in Dob's Linn gorge in the United Kingdom. But to geologists, this slice of shale represents one of

the major transitions in Earth's history. It is the location for a "golden spike," an internationally agreed-on marker for the boundary between two different geological periods, eras, or epochs. In this case, the golden spike marks the boundary between the Ordovician and Silurian periods, two planetary states so different from each other that, to geologists, the rocky evidence for each is clearly distinguishable. The Ordovician ended some 445 million years ago as rapid glaciation and other global changes triggered the planet's

fifth mass extinction event, wiping out more than 60% of marine life.

Now, scientists say, the planet has crossed another geological boundary, a transformation that will leave its own signature stripe in the rocks—and humans are the change-makers. An influential group of geologists, ecologists, and biologists argue that humans have so changed the planet that it is entering another phase of geological time, called the Anthropocene, "the Age of Man." Humanity, they contend, can be considered a

CREDIT: NASA (EARTH IMAGE)

geophysical force on a par with supervolcanoes, asteroid impacts, or the kinds of tectonic shift that led to the massive glaciation of the Ordovician.

"The Dob's Linn golden spike marks a revolutionary period in the Earth's history," Zalasiewicz says. "I feel quite the same sense of awe when I think about the kinds of large-scale geological changes that we are making to our planet now."

From the invention of agriculture and domestication of animals to the creation of cities, humans have been altering the landscape ever since the Holocene epoch began 11,500 years ago at the end of the last ice age. But, until recently, people have only changed their local environments. The industrial revolution increased the extent and reach of our impact, making it truly global. And after World War II, the system-wide human effect on our planet accelerated dramatically to the extent that the human-wrought changes may be considered comparable, many scientists say, to geological transformations of the past, like that of the Ordovician to the Silurian.

It was Nobel laureate Paul Crutzen who first came up with the term "Anthropocene." In an article in *Nature* in 2002, Crutzen argued that human changes have moved the planet out of the Holocene into a much less climatically stable age. The notion took hold. A wide range of scientists have used the term to describe our unprecedented, planetwide environmental effects, some of which are immediately obvious from satellite images of Earth. But formally accepting the Anthropocene as a geological term is a more controversial matter. After all, changes that appear vast from our human perspective might be invisible on a geological time scale. And debates over designating a new epoch, era, or period can take decades—even centuries—to resolve.

In 2009, the International Commission on Stratigraphy, the body charged with formally designating geological time periods, decided the Anthropocene concept "has some merit." It set up the Anthropocene Working Group, chaired by Zalasiewicz, to investigate the proposed age and report back. This February, members of the group published their initial findings in a special issue of the *Philosophical Transactions of the Royal Society A*. The group reported a wide range of human impacts on the planet that will leave a stratigraphically significant mark on the geological record.

Although he may often sound like an Anthropocene convert, Zalasiewicz says he hasn't officially made up his mind. "What

we're trying to do is to ask how different is our current world from that of a prehuman equivalent. And to what extent is the present state of the planet and its various changes in biology, chemistry, geography converted into geology?" he says.

The Anthropocene debate is continuing next week at the 2011 Geological Society of America conference in a session chaired by Stanley Finney, a geologist at California State University, Long Beach, who is the current chair of the International Commission on Stratigraphy. Finney is one of the most outspoken skeptics of the Anthropocene designation. He agrees that humans are changing the planet but questions how much of a mark will be left in the strata. "Many of our visible impacts could be removed through erosion," he says.

The writing in the rocks

Erle Ellis, an ecologist at the University of Maryland, Baltimore County, comes down firmly on the side of designating a new epoch, a view colored by his investigations into how humans have altered the planet's land covering. Ellis, a member of the Anthropocene Working Group, calculates that 80% of Earth's land surface has been modified by humans, with about 40% currently being used to produce food—a figure that doesn't include land used for timber plantations. Such deforestation and conversion to cropland or savanna leaves clear signs in the geological record; palynologists, who study pollen paleontology, can date human-kind's ancient agricultural forays with great accuracy. The current unprecedented rate of deforestation—80,000 km² per year—will also be easy to spot in the rock record, Ellis says. There are now more trees in agricultural land than in forests.

The human impact on biodiversity will influence the types and dispersal of fossil remains. "Biostratigraphy is a very effective way of recognizing one's place in deep time," Zalasiewicz says. Consider that more than 90% of total vertebrate biomass today is made up of humans and domesticated animals, up from 0.1% 10,000 years ago. And if the prediction of some biologists comes true, Earth will experience the sixth mass extinction event in its 4.5-billion-year history because of hunting, overfishing, habitat loss, pollution, and climate change; that would offer another, sobering piece of evidence for the Anthropocene.

Although humans have changed Earth's biota and its hydrology through damming rivers, creating reservoirs, sucking dry aquifers, and melting glaciers, the geologists who will ultimately judge the Anthropocene case may end up focusing more on alteration of the planet's lithosphere, its rocky shape. Some suggest that humanmade infrastructure will fashion a unique and enduring strata. "In the eyes of a geologist, we're making really quite interesting patterns out of our raw materials," Zalasiewicz says. "Wherever a road was buried, it would look like a rather strange and distinctive fossil river channel, but one which is quite rectangular in shape and with a particular pattern of gravel and other materials like concrete that are not typical of river channels. Millions of years from now, a geologist would see this and raise an eyebrow. A lot that we're producing is distinctive."

Cities, too, would leave their marks. Some may erode away, but others, particularly those like Amsterdam or New Orleans that are in low-lying coastal zones and could become "fossilized" as sediments accumulate over them, would leave their signatures of foundations, plumbing, and rubble in the lithostrata. "Peel back the pavements and the human interventions are already writ in the rocks," says Simon Price, an urban geoscientist with the British Geological Survey. "We're witnessing a geological process, but it's by our hands, not by glaciers or rivers."

Humans are changing the lithostratigraphy in now easily visible ways. Mining and other excavations remove four times as much sediment as the world's glaciers and rivers move each year, and massive land-forming projects have created entire islands in the United Arab Emirates and elsewhere.

Other anthropogenic changes are not obvious from Google Earth but will leave an enduring legacy. Long-lasting alterations to the planet's chemistry are already evident: The world is currently being flooded with light carbon (the C-12 isotope rather than C-13) due to fossil-fuel burning, and there is now a measurable difference—consistent around the world—in the carbon composition of biological specimens such as sea shells, coral, and the shells of plankton foraminifera, which will be preserved in the strata. Chemostratigraphy will also reveal the appearance of novel chemicals, such as PCBs, plastics, radioactive isotopes like cesium from atomic tests (see sidebar, p. 37), and newly common materials, from metals such as aluminum (which doesn't naturally appear in its elemental state) to nitrates

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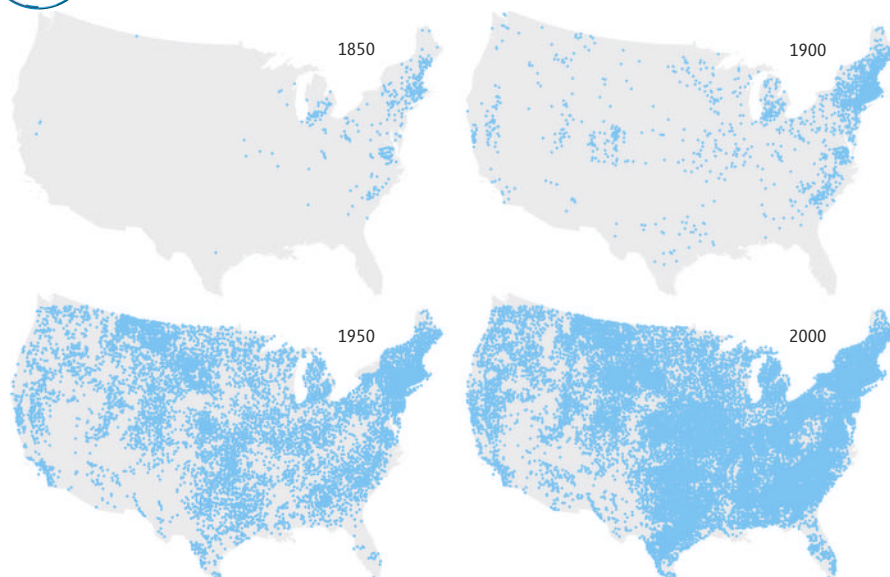
Podcast interview
with author
Gaia Vince.

A Global Perspective on the Anthropocene

Ever since humans launched Sputnik into space, we've been able to observe our planet and its changes from a truly global perspective. Satellites and improved data collection and analysis have allowed scientists to measure the anthropogenic influence on a range of Earth systems, enabling researchers to track rates of deforestation in the Amazon, Arctic ice melt, trails of air pollution, the extent of sea-level rise, and many other regional and global phenomena. These tools are enabling scientists to look at human changes to the planet's atmosphere, hydrology, lithosphere, and biota—and infer which changes are profound enough to be measurable millions of years hence.

WATER

Growth of U.S. Dams and Reservoirs

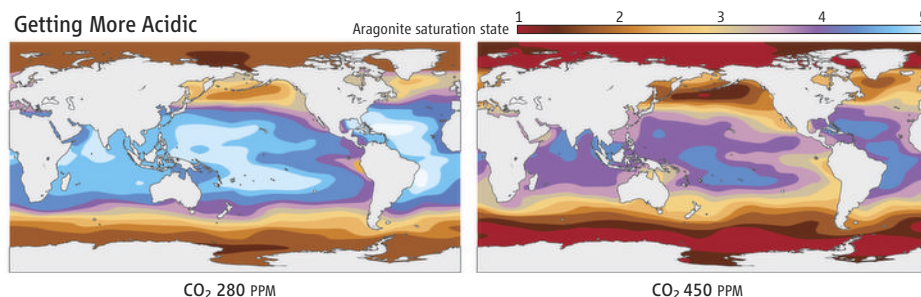


SOURCE: JAMES P. M. SYVITSKI ET AL., *PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A* 369, (2011)

Humans are increasingly exerting control over Earth's fresh water, through reservoirs, dams, and canals.

And as atmospheric carbon dioxide (currently at 392 ppm) increases, the ocean is becoming more acidic, as shown by the decreasing saturation state of aragonite (right). Aragonite is a type of calcium carbonate that many ocean creatures use to build their shells.

Getting More Acidic



CO₂ 280 PPM

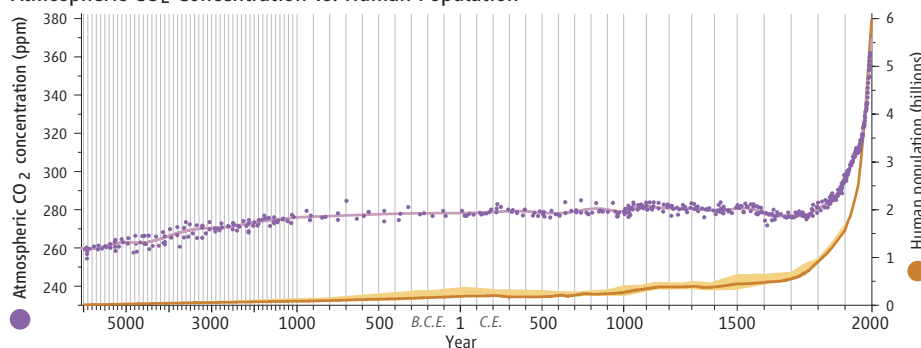
CO₂ 450 PPM

SOURCE: O. HOEGH-GULDBERG ET AL., *SCIENCE* 318, 5857 (14 DECEMBER 2007)

AIR

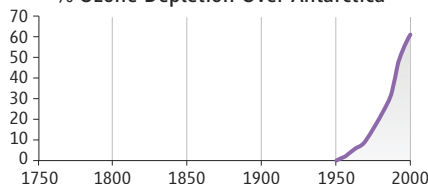
We can't directly see many of the changes we've made to our atmosphere, although we can measure the chemical pollutants and isotopic changes. Indirectly, though, we can feel the global warming effect of releasing increasing amounts of carbon dioxide into the air.

Atmospheric CO₂ Concentration vs. Human Population

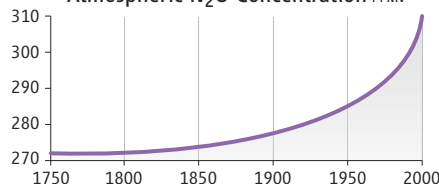


SOURCE: JED O. KAPLAN ET AL., *THE HOLOCENE* 21, 5 (AUGUST 2011)

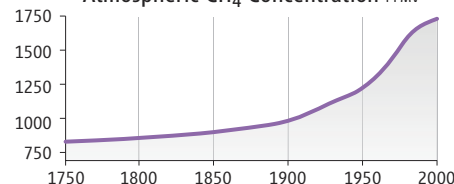
% Ozone Depletion Over Antarctica



Atmospheric N₂O Concentration PPMV



Atmospheric CH₄ Concentration PPMV



SOURCE: WILL STEFFEN ET AL., *PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A* 369 (2011)

LAND

Anthropogenic Transformation of the Terrestrial Biosphere

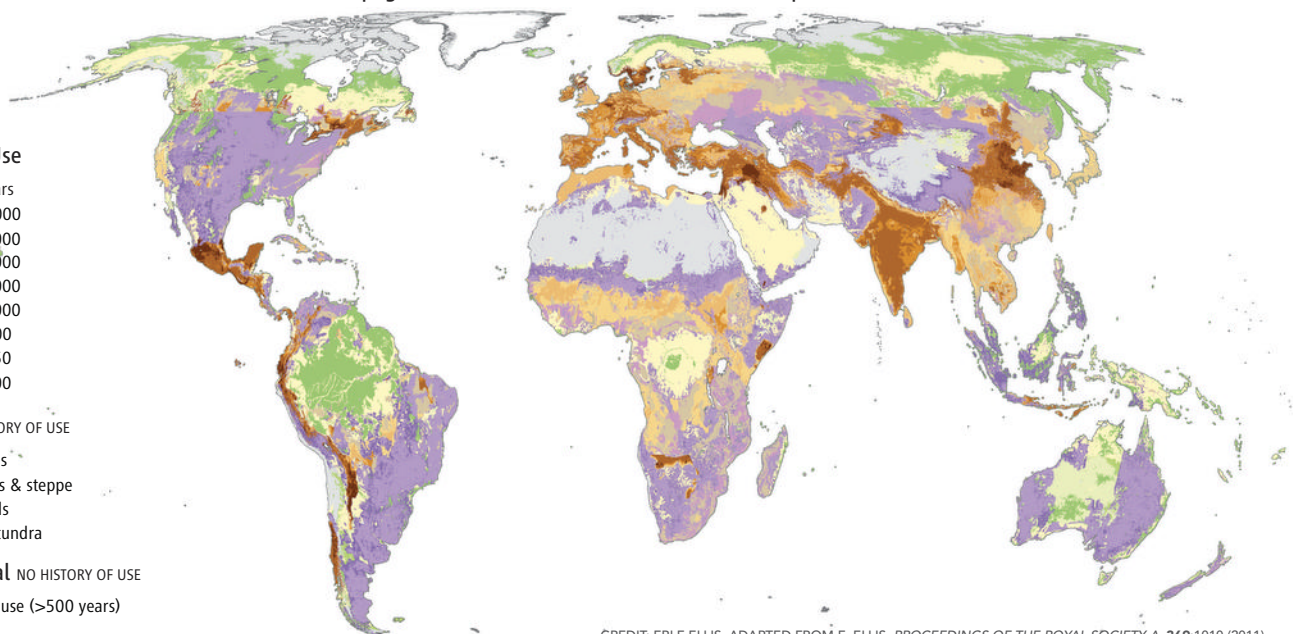
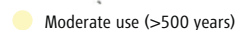
YEARS OF Intensive Use



Wild NO HISTORY OF USE

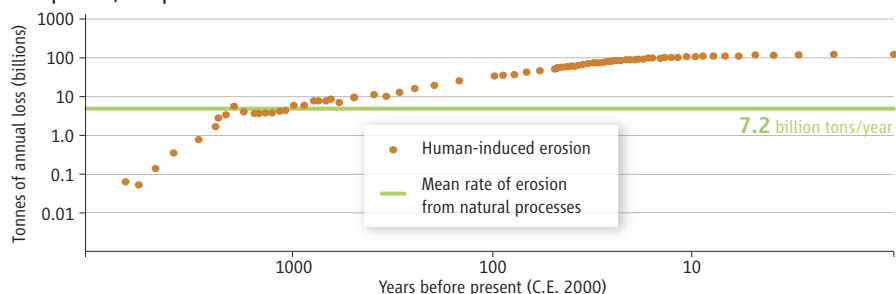


Seminatural NO HISTORY OF USE

CREDIT: ERLE ELLIS, ADAPTED FROM E. ELLIS, *PROCEEDINGS OF THE ROYAL SOCIETY A*, 369:1010 (2011)

Perhaps the most obvious mark we've made to the planet is in land-use changes. For millennia, humans have chopped down forests and moved rock and soil for agriculture and pastureland—and more recently, for construction.

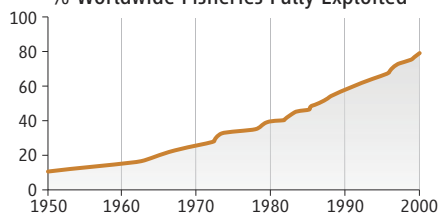
Deep Time, Deep Erosion: Who Erodes Land Faster?

SOURCE: BRUCE H. WILKINSON, *GEOLOGY* 33, 3 (MARCH 2005)

LIFE

Humans have boosted numbers of "useful" species such as cattle while depleting others through hunting, overfishing, habitat loss, or invasive competition. Some scientists believe humans will cause the planet's sixth mass extinction: Average species abundance of 3000 wild populations declined 40% between 1970 and 2000.

% Worldwide Fisheries Fully Exploited

SOURCE: WILL STEFFEN ET AL., *PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A* 369 (2011)

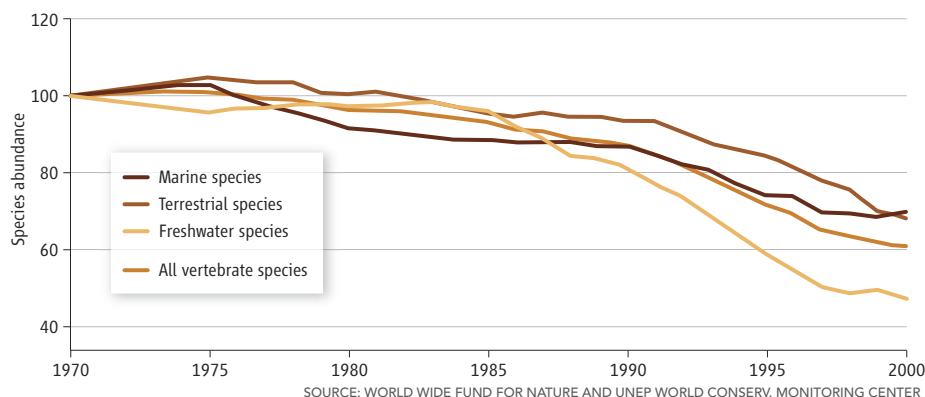
Domesticating the Planet

Consider that **90%** of total mammalian biomass is made up of **humans and domesticated animals** ...

... up from **0.1%** 10,000 years ago.

VACLAV SMIL, *THE EARTH'S BIOSPHERE: EVOLUTION, DYNAMICS, AND CHANGE*. MIT PRESS (2002)

The Fall of the Wild



SOURCE: WORLD WIDE FUND FOR NATURE AND UNEP WORLD CONSERV. MONITORING CENTER

A Sign of Our Times

If we are living in a new geological phase called the Anthropocene, when did it begin? In other words, where does its golden spike belong?

Many human-driven planetary changes have their roots in the industrial revolution, when the human population reached 1 billion. Atmospheric carbon dioxide from fossil fuels started to build from around 1800, although it probably took 50 to 100 years before new concentrations of light carbon accumulated in measurable levels in marine shells. That change could be the marker for the golden spike designating the beginning of the Anthropocene. There is a precedent: The boundary between the Paleocene and the Eocene epochs of the Cenozoic era is based on a change of carbon isotope chemistry.

But the scale of our impact accelerated rapidly after 1945 when population doubled (from 3 billion in 1950 to 6 billion by 2000). As a result, some think the golden spike—officially known as a Global Boundary Stratotype Section and Point—should be set around 1945, which handily provides a marker that's sudden, distinctive, and global: the introduction of radioactive nuclei into the environment from the first atomic-bomb tests in Alamogordo, New Mexico. "The golden spike could be put into a layer of accumulating lake sediments in which the radioactive cesium first appears," geologist Jan Zalasiewicz of the University of Leicester in the United Kingdom says.



Explosive signal. The atomic bomb tests of 1945 produced a sudden dispersal of radioactive dust that can be measured globally.

From a geological perspective, it doesn't matter whether the spike is at 1800, 1945, or 2050,



Reading the rocks. A geologist marks the "golden spike" of the Ordovician-Silurian boundary at Dob's Linn, Scotland, where a darker stripe in the shale reveals the first appearance of graptolite fossils (*inset*).



Zalasiewicz says, because millions of years in the future, with error bars of thousands of years, that kind of distinction will be impossible to perceive. Events that look abrupt in the strata may have taken millions of years to occur, and many changes take time to reveal themselves. For example, the temperature rise at the beginning of the Holocene was fairly abrupt, but it still took some 5000 years for sea-level rise to catch up.

"The golden spike we choose would be a time boundary that we use with full knowledge that most changes on Earth are happening in different places at different times," Zalasiewicz says. "It's useful and instructive to think of [the Anthropocene] from the far future perspective, but in practice we're dealing with it today. So we have to adopt as precise a time scale as we can."

—G.V.

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(which humans have made abundant through fertilizer production and fossil-fuel burning).

The nitrates in agricultural runoff also cause the massive dead zones that currently affect 250,000 km² of the world's oceans. Similar zones have been recorded in the planet's paleontological record, and the current ones likely will be as well. Ocean acidification, too, is a measurable result of anthropogenic carbon emissions being dissolved in the oceans—they are now more acidic than at any time in the past 800,000 years or more.

Challenging tradition

The working group is still gathering evidence that human changes such as these will leave an enduring legacy, then they will assess it and decide whether the Anthropocene should be formalized on the geological time scale, and if so, at what level: an age, epoch, era, or a period.

Finney questions how relevant the geo-

logical time scale is to the Anthropocene. In 100,000 years from now, people will not be digging the strata to find out about the world as it was in 2011, he argues; there are far better tools for that. Geologists now and in the future will use the human calendar and the many cultural records that are kept in order to look back to this time. The Anthropocene may be a useful general term, Finney says, but it has no place on the official stratigraphic time scale.

Ellis disagrees. "It's really helpful and relevant to think like a geologist, even though I'm not one. It frames our impacts on a bigger planetary perspective. To be able to look back at the rocks and say, 'Something happened here that cannot be explained by anything other than human impact' is really powerful," Ellis says.

"I think we're challenging the traditional view that geology always looks backwards. Geology is happening all around us now at a rate that we can certainly discern," says Will Steffen, executive director of the Australian National University's Climate Change Insti-

tute in Canberra. "Different eras and epochs in the past have been defined by changes in climate and biodiversity. We're already experiencing both of these, and for the first time we are aware of doing so and actually driving these changes."

Zalasiewicz's working group is aiming to deliver a final report at the 2016 International Geological Congress in South Africa. But there's unlikely to be a quick vote then on whether the Anthropocene deserves the title of epoch—or period or age. The Ordovician-Silurian boundary at Dob's Linn was finally agreed on in 1986, more than a century after its proposal by geologist Charles Lapworth. Only about half of the major boundaries in the Phanerozoic—our current geological eon covering the past 542 million years—have been fixed; the rest are still being argued over. Geologists, like their subject, are resistant to rapid change.

—GAIA VINCE

Gaia Vince writes on environmental issues in the developing world at wanderinggaia.com.