The Anthropocene debate and its ramifications for humanity

Jan Zalasiewicz, University of Leicester, UK and Julia Adeney Thomas, University of Notre Dame, USA.

Abstract: *The Anthropocene, was launched into public debate by Nobel laureate Paul Crutzen in 2000, when he saw that applying the term 'Holocene' to the present day no longer made sense. The Holocene is the formal geological epoch that represents the time since the last ice age ended nearly 12 millennia ago; it is the time of relative planetary stability that allowed complex human civilizations to develop and prosper. Crutzen argued that recent human impacts to atmosphere, ocean and biosphere had been so severe that this Holocene stability had ended, and that a new epoch marked by planetary instability and changes beyond Holocene norms had begun; he termed this the Anthropocene. Crutzen's proposal received both support and criticism: regarding the latter, it was argued that the Anthropocene was too short to be a geological epoch, or that it did not represent all human impacts that stretch back many millennia, or that it was politically, rather than scientifically, motivated – and these misgivings led to rejection of the Anthropocene as a formal Geological Time Scale unit in March 2024. Nevertheless, the evidence gathered by the Anthropocene Working Group (AWG) has shown that Crutzen's hypothesis is true beyond any reasonable doubt. There can be no doubt that the Earth has departed from Holocene conditions to become hotter, biologically degraded and more polluted; its biogeochemical cycles no longer function as they once did. These changes, closely linked to the mid-20th century 'Great Acceleration' of human population, industrialization and globalization, have left a distinctive and striking geological record; and, they are mostly irreversible, setting the course for a sharply distinct new trajectory of Earth history. The Anthropocene exists* de facto *if not yet* de jure *as a formal epoch, the trajectory of which will* inter alia *increasingly affect – and threaten – the lives of billions of people. As a consequence, the abundance and relative predictability that we have taken for granted as foundational to modern life with its particular forms of economics and politics no longer exists. The situation requires the courage to embrace a new set of principles and values appropriate to the new world of the Anthropocene, and to eschew business-as-usual. The Anthropocene, thus, represents an altered reality that we are struggling to understand and come to terms with. Our choices will define our planet's habitability for the foreseeable future.*

The Anthropocene concept, for all practical purposes, emerged on February 2000, In Cuernevaca, Mexico, where a meeting of the International Geosphere-Biosphere Programme (IGBP) was taking place. The focus of discussion was how the Earth System was changing in response to growing human impacts. A succession of speakers were presenting information on different kinds of change, to the atmosphere and oceans, to the landscape and its diminishing biodiversity, and kept referring to this change as taking place within the Holocene Epoch, the 11.7 thousand-year-long geological time interval that marks the time since the end of Earth's latest glaciation. Paul Crutzen, an atmospheric chemist and Nobel laureate for his research into human-caused change to the ozone layer, visibly grew irritated as the presentations went on. Eventually, he burst into the debate, to interject that it no longer made sense to say that we were living in the Holocene, because the Earth had changed too much. 'We're in the … Anthropocene', he declared.

It was an improvisation, but it stuck. Much of the subsequent discussion at the meeting was taken up with the idea and, with the support of the then Chair of the IGBP, Will Steffen, Crutzen pursued the idea. He discovered that Eugene Stoermer, a Canadian lake ecologist, had independently developed the idea and invented the term some years earlier, though only to use it in discussions with his colleagues and students. Nevertheless, he invited Stoermer to co-author a short paper introducing the Anthropocene concept to a wider audience, publishing it in the IGBP Newsletter that same year (Crutzen and Stoermer 2000). Later, he published a brief, vivid introduction – just one page – that reached a yet wider audience in the leading journal *Nature* (Crutzen 2002). The Anthropocene quickly became a framework concept for the scientific work of the IGBP and more generally the wider Earth System science community, comprising scientists who tried to study the Earth as a whole, integrated system rather than simply through its separate components as had become the norm with the increasing specialization of science, especially from the mid-nineteenth century onwards (Schellnhuber 1999). This community treated the Anthropocene as a *de facto* epoch of post-Holocene time, with Crutzen initially suggesting that it might be thought to have begun around the beginning of the Industrial Revolution in the late 18th century, when fossil fuel burning began in earnest in Europe. Including few geologists in their ranks, they were unaware of, or disregarded, the complex bureaucratic procedures that had built up over some two centuries to add new geological time units formally to the Geological Time Scale – so they simply used the term matter-of-factly as a new epoch in their publications (e.g. Meybeck 2001, Steffen *et al*. 2004, 2007). For geologists, however, words with the suffix '-cene' are technical terms indicating a particular type of time interval within the Cenozoic Era that represents the last 66 million years of Earth history.

Eventually, the geological community noticed that 'Anthropocene Epoch' was being used in publications emerging from the IGBP community, even though the term had not gone through any of the complex procedures of the official committees overseeing the way Earth's history is divided up on the geological time scale. One such committee began discussing this term in 2006: the Stratigraphy Commission of the Geological Society of London. Although it was a national committee and not an international one, and hence had no jurisdiction over the Geological Time Scale, it was able to analyse the issue and voice an opinion. It found (Zalasiewicz *et al*. 2008) that the concept had merit, and needed further study.

This finding led to the decision to create a formal working group to officially examine the issue. A working group, in this case the Anthropocene Working Group (AWG), is the lowest rung of the extensive hierarchy that polices the Geological Time Scale. The AWG was set up by the Subcommission on Quaternary Stratigraphy (SQS), the body that deals with the timescale of the Quaternary Period that represents the last 2.6 million years of Earth history (essentially, the Ice Ages of common parlance). The SQS is a division of the International Commission on Stratigraphy (ICS) which oversees the entire Geological Time Scale. The ICS itself is under the jurisdiction of the International Union of Geological Sciences (IUGS), the overarching body for geology as a whole.

In 2009, the AWG started work. Of necessity, it broke some precedents. Because in the Anthropocene geological time clearly overlaps with historically-recorded time, the membership needed to include not only geologists (especially of the subdiscipline stratigraphy, which studies Earth history from the evidence contained within rock strata), but also historians, archaeologists, Earth System scientists (Paul Crutzen and Will Steffen became members), oceanographers and others (including a lawyer specializing in the International Law of the Sea, to help consider the wider utility of the term and concept to society). Thus, rather than a specialist stratigraphic body, it developed from the start as a multidisciplinary one (Thomas *et al*. 2020) – the first such in the ICS.

Nevertheless, the AWG was working within the framework of geological time, which has two aspects. Geological time concerns itself both with time understood as the temporal flow of history, and with time in solid, *material* form: e.g. the physical strata of the Earth's crust (Zalasiewicz *et al*. 2013). Specifically, geologists work to establish whether the strata that formed during any given interval of time are distinctive enough (through their fossil content, their chemical patterns and so on) that they can be recognized as distinctive units, and traced ('correlated', in geological parlance) around the world. For geologists, this makes sense, because almost always their only contact with time is through the rock record, more than 99% of which was formed before humans emerged and were able to observe and then record what was going on around them. Thus, the Anthropocene not only had to make sense as an *epoch* of historical time with significant rises in production, consumption and human population significantly altering the planet's climate, diminishing biodiversity, terraforming the Earth's crust, and increasing pollution, but also as a *series* comprising sediment layers that trapped systematically recognisable evidence of those environmental changes. Paul Crutzen, Will Steffen and their colleagues were thinking only of these environmental changes over time – while for most geologists, it is the physical *series* that is crucial, as that is the direct link with the Earth's history as deduced from ancient strata.

The *boundary* of a geological time unit is crucial, too, for that must, as far as possible, be traceable *synchronously* around the Earth, using evidence preserved in the strata. The synchronicity is important, for most environmental changes on Earth take place *diachronously*: that is, they happen at different times in different regions of the Earth. For instance, when global climate changes, it takes some significant time for glaciers to respond, by advancing in colder climates and retreating in warmer ones, and similarly animal and plant populations take centuries or millennia to migrate in response to such climate changes. To chart these phenomena through space and time, a practical, reliable time framework is needed, and the boundaries of geological time units serve as its main rungs. The boundary for the Anthropocene originally suggested by Crutzen, the beginning of the Industrial Revolution in Europe in the late eighteen century, seemed the obvious one as regards atmospheric change and Western environmental history – but did it work *geologically* and as *global history* too?

When the AWG began its work, there was no clear evidence that the striking global environmental changes identified by Crutzen and his colleagues had produced a corresponding, recognisable unit of strata, distinct from the strata of the Holocene. After all, most geologists work on much older rocks (though there has long been a thriving community devoted to the Holocene), and think in terms of millions of years, not centuries or decades: they use hammers and chisels to gather data, rather than spades and trowels.

Nevertheless, the evidence gleaned from modern strata began to build up (e.g. Williams *et al*. 2011, Waters *et al*. 2014) – and to mirror the observed and recorded evidence of global environmental change documented by the Earth System science community (Steffen *et al*. 2016; Zalasiewicz *et al*. 2017a). The burning of fossil fuels, for instance, is taking carbon stored for hundreds of millions of years underground – and suddenly, well-nigh explosively, releasing it into the atmosphere and oceans. The resulting rise in carbon dioxide in the atmosphere can now be measured instrumentally, and this rise has been documented systematically as the 'Keeling curve' (named after the scientist Charles Keeling, who started it) since 1958. It has taken atmospheric carbon dioxide to levels far higher than at any time in at least the last 800,000 years, as shown by comparison with fossil air trapped within layers of Antarctic ice. The rise has been extraordinarily quick – about 100 times more quickly, indeed, than the rise in carbon dioxide that took place as the Earth warmed from the Pleistocene into the Holocene epochs (itself considered a rapid rise in a geological context) (Figure 1).

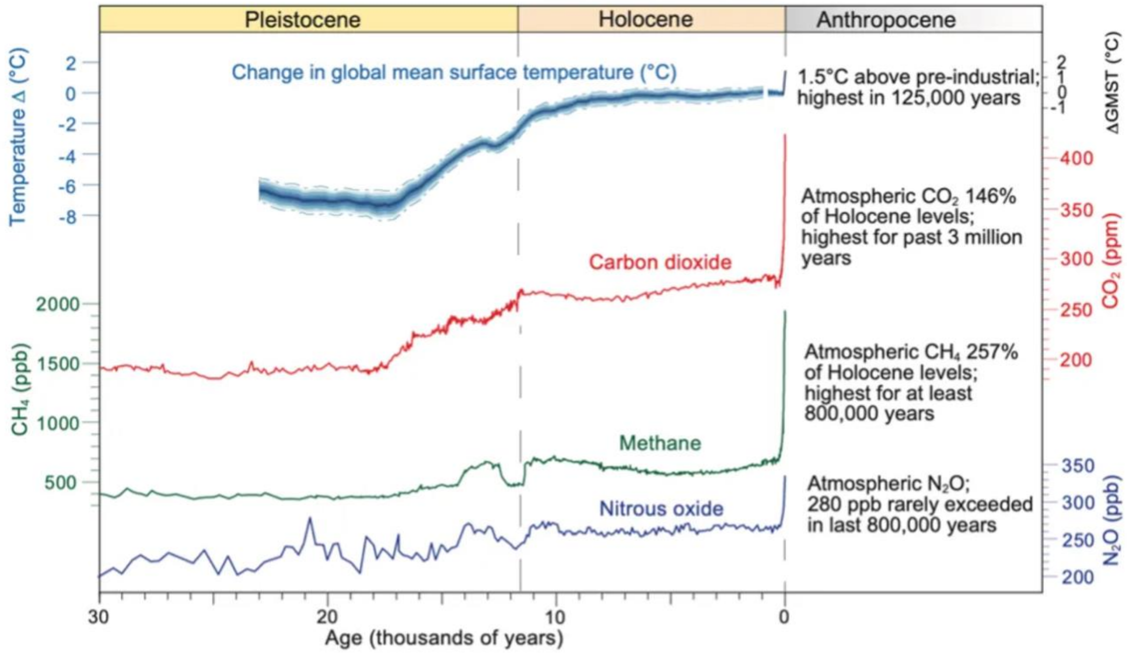

Figure 1. *Key Earth System metrics such as the concentrations of carbon dioxide and other greenhouse gases in the atmosphere, and the global temperature change that results, rose significantly from the Pleistocene into the Holocene epochs, as this 30,000 year graph shows – but nowhere near as abruptly as in the change from the Holocene to the Anthropocene. Diagram courtesy of Martin Head, originally published in Turner et al. 2024.*

This ongoing carbon dioxide rise leaves other, more material, clues too. Fossil fuels have a distinctive chemical fingerprint, in being relatively rich in the light carbon-12 isotope, and this isotopic fingerprint is being incorporated in growing (and fossilizeable) carbon-based materials, such as tree wood and coral skeletons. The high-temperature burning of fossil fuels in industrial furnaces and power stations produces countless carbon-rich fly ash particles too, released in smoke, carried far and wide in air currents and then falling to earth; these fly ash particles can be recovered from sediment layers in peat bogs and lakes (and have even been found in Antarctic ice layers). They provide solid and near-ubiquitous evidence that can be used to recognise the Anthropocene in strata.

Many other lines of evidence turned up. Plastics, for instance, have been dispersed worldwide by wind and water currents, and are now present in sediment layers from the tops of mountains to the ocean depths, both as large recognisable objects such as discarded drinks bottles and food wrappers (that may be regarded as 'technofossils') and as tiny microplastic fragments (Zalasiewicz *et al*. 2016). Many kinds of modern persistent organic pollutants, such as pesticides, can be detected in modern sediments. The way we have changed animal and plant communities too has left its mark geologically – not so much, yet, because of the growing extinction crisis, but because of the human-driven translocation of many thousands of species, both intentional and accidental, between every continent and every ocean on Earth. The fossil remains of these recently introduced species already characterize many sedimentary successions (Williams *et al*. 2022, 2024). Even before Crutzen's suggestion of the Anthropocene, this phenomenon had led to the independent suggestion of a 'Homogenocene' epoch (Samways 1999) to reflect the homogenization of the Earth's long-established biogeographic communities.

As the evidence in support of the Anthropocene accumulated, though, it became clear that Crutzen's originally suggested starting point, the beginning of the Industrial Revolution, would not be easily workable geologically, because the geological signals associated with the beginning of the Industrial Revolution in Europe were too slight globally and too scattered in time and space; they were diachronous, rather than synchronous, because of the way that industrialization spread piecemeal around the globe over more than a century and was not fully unleashed until the twentieth century. But another, far more convincing level for a Holocene-Anthropocene boundary had become apparent by 2004 with the work of an IGBP team lead by Will Steffen. In a report titled "Global Change and the Earth System: A Planet under Pressure," they correlated the growth of human factors such as population, GDP, and Direct Foreign Investment with clearly defined rises in greenhouse gases, a transformed ocean, and ecosystem and species losses. Putting together this sociopolitical and environmental evidence showed that an abrupt change occurred, not in the late eighteenth century, but in the mid-twentieth century when the world experienced the 'Great Acceleration' (McNeill's term: Steffen *et al*. 2007, 2015). From this point on, the effects of human pressures on the Earth System produced a cascade of geological signals in the strata that made this new period of time not just a historical unit but also a geological one (Zalasiewicz *et al*. 2015; Kuwae *et al*. 2024). It became apparent that using ~1950 as the starting point of the Anthropocene Epoch was far better because it reflected the planetary transformation as the relative stability of the Holocene Earth System gave way to the more unstable and rapidly evolving conditions of the Anthropocene.

The Great Acceleration is a striking phenomenon. For instance, more than 90% of the coal, oil and gas ever exploited have been burnt since 1950, and humanity has used more energy since 1950 than in the whole of the 11,700 years of the preceding Holocene (Syvitski *et al*. 2020). Mining, damming, urbanization and soil loss due to expanded agriculture have transformed the terrestrial landscape in this period. Many key signals – such as of plastics and many persistent organic pollutants – are essentially confined to the post-mid-20th century interval. And, the most precise signal of all is provided by artificial radionuclides, generated by nuclear bomb testing and civil nuclear power, specifically with the worldwide spread of plutonium that followed the beginning of thermonuclear hydrogen bomb (H-bomb) testing in 1952 (Waters *et al*. 2015). The detonation on November 1, 1952 of the "Ivy Mike," the first H-bomb, was identified by the AWG as a suitable 'primary marker' that could guide definition of the Anthropocene, being a modern, technologically-created analogue to the meteorite-scattered iridium that forms a striking, essentially synchronous global boundary marker for the Cretaceous-Paleogene boundary notoriously associated with the mass extinction event that killed off the dinosaurs, 66 million years ago.

By 2016, the AWG had gathered enough evidence to state that the Anthropocene was real both historically and geologically (Waters *et al*. 2016; Zalasiewicz *et al*. 2017b, 2019). In other words, the evidence reflects the sharp and in many respects irreversible (for all practical purposes: Summerhayes *et al*. 2024) transformation of the Earth System from Holocene conditions: that is, the Anthropocene epoch as part of Earth's history as conceptualized by Crutzen. It also shows a corresponding unit of strata characterized by many geological signals with its beginning (or technically, base, as we are talking about physical units of strata) precisely defined by that synchronous worldwide rise in plutonium content. In short, the Anthropocene made sense both in terms of Earth System science and in terms of geology (Steffen *et al*. 2016; Zalasiewicz *et al*. 2017a). The next step was to prepare a formal proposal to be considered by successive committee stages above the AWG in the geological time scale hierarchy.

But already, despite the clear evidence accumulated by the AWG that Crutzen's improvised hypothesis of 2000 was fundamentally correct, substantial opposition to formalizing the Anthropocene was gathering. That opposition comprised several strands, of which two may be noted here.

Firstly, within the geological community, some of the most senior and influential figures among those determining the geological time scale voice outright opposition to formalization. They do not question the AWG's evidence, but simply cannot accept a geological epoch of such brevity, so far just some seven decades, approximating the average human lifespan. For these geologists, used to dealing with millions of years, such a short recent epoch is *a priori* unacceptable. They also claim that due to this brevity, the Anthropocene strata must be negligible in thickness, ignoring that in reality, global erosion and sedimentation since 1950 have accelerated more than tenfold, to produce substantial as well as distinctive strata. And, they averred, the Anthropocene should not be part of geology because it dealt with the future, while geology should concern itself only with the past. Again, not so. As the AWG found, those seven decades have already produced considerable planetary change, and distinctive new strata. These assertions reflect a visceral (and continuing) rejection of the uncomfortable new concept of the Anthropocene, within a powerful part of the geologically community.

There are also objections among scholars who deal with the deep human past such as archaeologists and anthropologists. They voiced concern that the Anthropocene excluded most of human history – and therefore most of the time during which the 'anthropos' of the term's prefix was active. The Anthropocene, they said, began many thousands of years ago – and in any case should be flexibly, and not precisely, defined, to accommodate a wide range of interpretations and interpreters. This observation is true in that human influence on the Earth (on land, at least) goes back many millennia, to the pre-*Homo sapiens* control of fire, the hunting to extinction of many large mammals, the development of agriculture, and so on. But they miss the point. Crutzen was perfectly aware of the long history of human/environment interactions, but emphasized that this long history with its rich archaeological record had not destabilized the Holocene or the earlier Pleistocene. Rather, despite human activities, the Holocene had been essentially stable in planetary terms: as regards climate, sea level, the carbon, nitrogen and phosphorus cycles and a functional biosphere. This stability, unusual in the last 2.6 million years of the Quaternary ice ages, allowed human civilization to develop and flourish. It was the upending of this Holocene stability by *overwhelming* human impacts stemming from industrialization that was Crutzen's key insight – and the basis of the AWG's work. 'Anthropocene', here, does not mean 'all things anthropogenic'. Perhaps, had Crutzen chosen some other term on the spur of the moment, this confusion might have been avoided, but it is unlikely that any single term can encapsulate the full magnitude of the transformation of the Earth System by human systems, and people, being people, would always find fault.

For most of its existence, the AWG has been responding at length to critiques of this kind (e.g. Autin and Holbrook, 2012; Finney and Edwards, 2016; Gibbard *et al*. 2022) The ensuing discussion represents a substantial part of its published output (e.g. Zalasiewicz *et al*. 2017c, 2024a; Head *et al*., 2023; Waters *et al*. 2023a) . It has been a useful exercise in that it has thoroughly tested the Anthropocene concept in theory and practice, though opposition to a formalized Anthropocene did not stop once the objections voiced were answered, or as the evidence base demonstrating the Anthropocene's reality built up. Rather, the opposition became if anything more forceful, suggesting that we are dealing here with a question in which philosophical or ideological convictions (on what geology should and should not include within its purview) played a larger part than the weighing of detailed evidence, whether from Earth System science or from stratigraphy.

This published debate carried on after the AWG's 2016 announcement (Zalasiewicz *et al*. 2017b) while the working group began preparing its formal proposal. In classical geological fashion, this highly technical research sought to locate a 'golden spike' (technically, a Global boundary Stratotype Section and Point, or GSSP) in some section of strata that, through its pattern of geological signals, would seek to best represent the beginning of the Anthropocene. This complex exercise, unlike the work done on older, long-used geological time scale units, did not have a century or more's work, data and academic connections to fall back on; with the Anthropocene, it was a question of starting from scratch.

The exercise was only possible because of a remarkable windfall to the previously wholly unfunded AWG. Berlin's Haus der Kulturen der Welt (HKW), a humanities-based institution led by its Director Bernd Scherer, had taken an early interest in the Anthropocene, organizing the first major public exhibition on it in 2014, and continuing to initiate multidisciplinary activities on its theme. Bernd Scherer obtained funding from the German government for the many scientific analyses needed to establish the basis for a formal Anthropocene boundary (Rosol *et al*. 2023). These welcome funds allowed 12 teams of scientists to analyse and compare 12 sites around the world, representing different types of recent strata including annually-formed lake-and estuary-bed layers, cave deposits, a peat bog, coral skeletons – and the rubble layers beneath the centre of Vienna – for evidence of precisely how, layer by layer, the Holocene gave way to the Anthropocene.

This very large exercise, achieved within three years (despite the ongoing Covid pandemic) showed, at all 12 sites, clear evidence of the Anthropocene on the basis of a wide range of signals preserved within the strata (Waters *et al*. 2023b). At an exceptionally closely studied site in Japan, the team found, remarkably, 99 different kinds of human-caused or -influenced signals recorded in the core samples of Beppu Bay. As predicted, the plutonium signal provided the sharpest and most synchronous signal, in several cases being recognisable to the nearest year. The exercise demonstrated the reality of the Anthropocene as a geological phenomenon. After much discussion within the AWG, one of the 12 sites, Crawford Lake in Canada, was chosen – by very fine margins – as the candidate for the Anthropocene 'golden spike', with some of the others given auxiliary status, the rest being named reference sections. All sites were significant in building up a picture of the geological Anthropocene.

Crawford Lake became the centrepiece for the 190-page proposal for formalization of the Anthropocene submitted at the end of October 2023 to the next rung of the hierarchy, the Quaternary Subcommission (SQS) (Waters *et al*. 2024). In controversial circumstances, the proposal was rejected though an announcement made by press release to the *New York Times* on March 5th 2024. Despite a number of irregularities in the process, the decision was upheld by the ICS and IUGS. The decision reflected the continued hostility, especially at senior levels of the geological time scale community, to the Anthropocene concept of Crutzen and the AWG. As with earlier critiques, little of the detailed evidence assembled by the AWG was queried.

Where are we now? The Anthropocene as conceptualized by Crutzen and developed in geological terms is undoubtedly real, even as it remains informal. The Earth System has shifted profoundly in the mid-20th century from its Holocene state; this shift has left a pattern of signals in strata as clearly distinctive as any in the geological record; and, this change is irrevocable (there is no going back to a Holocene state). Most importantly, the emerging Anthropocene Earth System is defining (and in most cases, reducing) the habitability of our planet, not only for our own species, but for most others too.

The denial of formal recognition by the committees controlling the geological time scale has not effaced this reality. An analogy might be made with some of the prior conceptual revolutions in geology: for instance, the realization that animal and plant species were not immutable but evolved through time; the understanding that there had been past Ice Ages; and, the knowledge that the Earth's continents were not fixed but slowly drifted across the globe. In each of these three cases, there was at first fierce resistance to the new paradigm overturning long-held conceptual and methodological beliefs among geologists. It took decades, and new generations of scientists, for the new ideas to be accepted (e.g. Oreskes 1999). Within geology, we seem to be exactly at such a stage with respect to the Anthropocene. But more widely, the Anthropocene as a term and precisely used concept is spreading, with multidisciplinary research institutes devoted to the Anthropocene appearing, in China, South Korea, Germany, South Africa and elsewhere, and with the Anthropocene being used as a framework concept by institutions such as the IPCC and WWF (Zalasiewicz *et al*. 2024b).

The Anthropocene and Our Common Home

In the context of this workshop, and this publication, though, the real importance of the Anthropocene is that sums up all the dangers threatening our common home. These dangers are manifold and inseparable from one another. What makes the concept of the Anthropocene so vital is that it brings together disparate phenomena, and helps us see the entangled networked whole so that we reject the siloed-thinking that has allowed us to imagine that nature and people could be studied separately and that the fate of some is separable from the fate of others. As opposed to the siloed-thinking that served to spur the Great Acceleration, the Anthropocene provides the framework for the systems-thinking needed to address the urgent dangers facing all of humanity. It calls on us to recenter our values and actions on what we share, including the 'joyful mystery' of life on this beautiful planet.

Below we address some of these dangers, stressing their interrelatedness and the need to approach mitigation using the Anthropocene framework. Because the physical planet and the human globe can no longer be seen as functioning in isolation from one another, a multidisciplinary approach is essential. No problem can be 'solved' in isolation from the biogeophysical and cultural-socioeconomic networks of which it is a part. As American conservationist John Muir put it, 'when we try to pick out anything by itself, we find it hitched to everything else in the universe.'

Climate change: this might possibly have been described as an ‘incipient’ threat back in 2000, when Crutzen launched the Anthropocene concept. Back then, the average global temperature was ‘only’ a little more than half a degree centigrade above its pre-industrial level measured from its standard 1850-1900 baseline – but it was clearly signalled, given the steep rise in greenhouse gas emissions in preceding decades. Since then, global warming has definitively arrived, as temperatures have progressed further in catching up with the change in the Earth’s radiative (i.e. heat) balance, especially after the record-breaking years of 2023-4 (~1.47°C and ~1.6°C above pre-industrial, respectively[1]). In 2024, temperatures broke through the upper limit of 1.5°C agreed as the desired maximum by the 2016 IPCC Paris Agreement. The long list of repercussions includes rising sea levels (now ~5 mm/year), increased de-oxygenation of the oceans, dislocated biological (including agricultural) systems, increasing risk of earthquakes, and more extreme weather events in a climate increasingly prone to ‘hydroclimate whiplash’ (Swain *et al*. 2025) including lethal heatwaves, forest fires, floods and crop failures.

Approaching climate change from the Anthropocene perspective underscores its potent menace – it has been described as being ‘poised to be the greatest injustice in history’[2] – but also shows that climate change mitigation cannot be treated simply as a matter of finding new ‘green’ energy sources without considering these sources’ impacts on other aspects of the environment and on societies. Two quick examples will suffice. A glance at the resource wars in the Democratic Republic of Congo make clear that mining for valuable minerals such as coltan used in computers puts human and non-human lives and social stability at grave risk. In the United States, meeting the exorbitant energy demands of Artifical Intelligence and data centres around Washington DC would require the construction of several large-scale nuclear plants.[3] Since endangering the nation’s capital in that way is off the table, energy companies (required to meet demand) are muscling into the prerogatives of rural county boards and insisting that land be zoned for large-scale windfarms to power the DC metropolitan area. Rural resistance to the transformation of their landscape has been met by state governments removing land-use issues from county board control (Yancey 2024). The political result of rural resentment against the elite is plain to see. In short, adoption of ‘green’ energy, if it is to help guide us along a safer trajectory, must weigh the benefits against the costs in land-use change, political stability, aesthetic beauty, and biodiversity loss. We cannot address the Anthropocene by siloed-thinking about climate alone as the IPCC now recognizes.

Biosphere decline: Beyond the intensifying effects of global warming, the biosphere continues to be diminished by habitat loss due to expanding human predation and

[1] https://climate.copernicus.eu/global-climate-highlights
[2] https://www.columbia.edu/~jeh1/mailings/2024/ICJ.PressBriefing.09December2024.pdf
[3] https://www.washingtonpost.com/business/2024/03/07/ai-data-centers-power/

human settlements and land use of many kinds including farms and mining. The biosphere's transformation has been remarkable, especially on land, where the biomass of mammals is utterly dominated by humans (about one-third) and farm animals (about two-thirds; and *inter alia* contributing significantly to greenhouse gas emissions): the world's wild mammals now make up just 2% by weight of all terrestrial mammals (Greenspoon *et al*. 2023). Ocean life is being rapidly degraded too, most visibly in the widely devastated coral reefs (Goreau *et al*. 2024). The thinning out of the web of life has damaged human health due to the increasing ease with which diseases spread from wild and domesticated animals to people. These health challenges (Gupta *et al*. 2024) have had political and economic effects as we all witnessed during Covid. Moreover, biodiversity loss threatens to diminish the human capacities for wonder and compassion. It is not by accident that animals and plants figured in myths and children's books as characters in their own right, with all the quirks of the actual species brought fully into the stories. We used to live in thickets of non-humanness marvelling at beings unlike ourselves. This was a training ground for the imagination and the compassion needed to see the world from the perspectives of others.

Technology: The recent planetary transformation has been mediated and enabled by another factor: technology. Technologies developed slowly throughout the Holocene and earlier times, but only recently have they exploded into dominance in tandem with Anthropocene forcings, becoming the integrated, globally networked technological system that now structures our lives. The growth of technological systems can be measured in many ways, but we might simply use the total mass of manufactured objects in current use (i.e. buildings, roads, machines etc) as a guide. In 1950, this mass was beginning to rise, but nevertheless totalled less than a hundred billion tons, or under 10% of the mass of all living things on Earth. Seven decades later, having been caught up in the Great Acceleration, this 'anthropogenic mass' had grown more than tenfold to over a trillion tons (Elhacham *et al*. 2020). The mass of things that human beings have engineered and built exceeds the mass of the biosphere, and it is still growing rapidly and evolving even more rapidly (as in the hyper-rapid evolution of computer systems in recent decades). Among the many items spewed out of it are plastics, pesticides, fungicides, lead, and other major pollutants that it cannot reabsorb, and so are destined to linger on the Earth for geological timescales (Gabbott and Zalasiewicz 2025). Annually, the solid wastes produced by municipalities around the world weighs about 2.01 billion tons, a figure that is anticipated to reach 3.40 billion in about 30 years (Filipenco, 2024). This phenomenon has been described as a wholly new 'sphere' of the Earth System: the technosphere (Haff 2017, 2019, 2023). Unlike natural spheres, this anthropogenic sphere is not regenerative. The technosphere emerged from the biosphere very recently and is now effectively parasitizing it.

Humans today are almost wholly dependent on the technosphere for our survival. Without its capacity to garner raw materials, to produce food, water, and needed articles, and to transport things to where they are consumed, countless deaths would ensue. Everyone relies on the technosphere for sustenance, energy, communications, and health all over the world at essential levels, and at luxury levels for the middle and upper classes.

Despite the technosphere being essential, societies, individually and collectively, have only very limited influence on it because our political systems were not designed to regulate global enterprises, and our knowledge systems do not comprehend it fully or understand its swiftly evolving forms. This emergent and constantly morphing system driven by path dependencies, specialist innovations, financial networks, and fiercely antagonistic aims and interests on the part of billions of people is essentially ungovernable. Increasingly, this emergent system seems able to do without its human components, automating jobs and rendering workers redundant. Understood in this way, technology is no longer a tool people use, but a system that uses people, shaping personal relationships (dating apps, social media) and societies (data centres, Amazon warehouses, political messaging). As Pope Francis and others have observed, although some technologies have advanced human welfare, the globalized technological system dominant today has created wide disparities of power and wealth, undermined our capacity for compassion, and alienated us from one another (*Laudato 'Si,* especially Chapter 3). Again, the challenge of the technosphere cannot be addressed in isolation from climate change, biosphere disruptions, politics, social mores and values which is why the Anthropocene is a vital framework.

Our Bodies: One of the boons of technology in the first decades of the Anthropocene was a revolution in human health. Due to sanitation systems, agricultural techniques, antibiotics, vaccines[4], and other new medical interventions—all aided by the capacity to spread these innovations through human development programs—the human population has grown from about 2 billion people to over 8 billion. Women do not die nearly as frequently in childbirth; the vast majority of children can expect to see their fifth birthday. Indeed, even in sub-Saharan Africa which suffers the highest rate of infant mortality, infant deaths fell from 180 out of 1000 in 1990 to 27 out of 1000 in 2022. (World Health Organization, https://www.who.int/news-room/fact-sheets/detail/newborn-mortality) At the same time, longevity for humans has been extended by many years. This is success by almost any measure (Desmond and Ramsey, 2023). But accompanying this human surge is the decline in non-human flourishing with the depletion of half the world's land-based biomass during the Holocene due to human predation (Bar-On *et al*. 2018) and the even more precipitous

[4] Vaccines have saved more than 150 million lives over the past 50 years and cut infant mortality by 40 percent worldwide. https://www.scientificamerican.com/article/see-how-many-lives-vaccines-have-saved-around-the-world/

biodiversity decline since 1990 (Ceballos *et al*. 2017). While we humans may live to enjoy old age, older wild animals are decreasing in number, eliminating experienced individuals who best know their environments and so impinging on their group's ability to thrive (Kopf *et al*. 2025).

A mere seven or so decades into the Anthropocene, we may have passed the point of peak health for human beings as the ills of the Anthropocene kick in. There is already some indication that life expectancy among some groups is beginning to drop. The dangers include heat (Xu *et al*. 2020), lack of fresh water, PFAS 'forever' chemicals and microplastics in every part of our bodies, including our brains. A recent Harvard study estimated that each of us ingests—through air, water, food, and the things that we touch—the equivalent of a plastic credit card each week[5]. These tiny undegradable fragments are able to traverse the umbilical cord so that babies today are born already imbued with plastic. We are also losing the war against antibiotic resistance. It is growing (by 80% since 1990 for people over 70) and could claim the lives of tens of millions in the next few decades with people succumbing to once were treatable infections.[6] Research is beginning to suggest that the vaccines that still work may be hampered by climate change[7]. Since the mid-twentieth century, new chemical compounds being pumped out in the millions of tons have entered our bodies through many pathways (Thomas 2014) Some of these compounds mimic the body's natural reproductive hormones rendering many species including warblers, polar bears, fresh-water fish, and alligators intersex (i.e. having the reproductive organs of both sexes) and sometimes unable to breed. Human fertility is also impacted by hormone-mimicking chemicals such as the highly toxic phthalates in plastic food packaging (Langston 2010). In short, our bodies are no longer chemically, microbially, and functionally as they were in the Holocene. During the initial stages of the Great Acceleration, many advances were beneficial, but it seems that in human health, as in other sectors, we are approaching a tipping point. *Laudato 'Si* urges all of us to care for our bodies, but caring for ourselves today raises new challenges.

Economic Growth: No idea is more important in initiating and driving the Anthropocene than the idea of infinite economic growth. Even now we cling to this notion like a deflating life raft. Economic growth is seen not only as desirable for family bank accounts and business enterprises but, since the 1930s, has become a central government responsibility. Initially in response to the Depression and then worldwide after World War II, all major nations dedicated themselves to spurring growth to support infrastructure projects, expanded social welfare, retirement funds, and military

[5] https://news.harvard.edu/gazette/story/2024/10/plastics-in-our-bodies-what-does-that-mean-for-our-health-harvard-thinking-podcast/
[6] https://www.nature.com/articles/d41586-024-03033-w
[7] https://www.nature.com/articles/d41586-023-04077-0?utm_source=Live+Audience&utm_campaign=e3f73c313e-briefing-dy-20240109&utm_medium=email&utm_term=0_b27a691814-e3f73c313e-50302812

strength. Whether capitalist, state capitalist, or communist, all states joined in. Growth enjoyed bipartisan momentum in the United States and in other allied nations where progress was measured by GDP, the tally of goods and services provided by the enterprises governments nurtured. West Germany produced the Wirschaftswunder (or 'Miracle on the Rhine') and France oversaw Les Trentes Glorieuses. Japan's Ministry of International Trade and Industry (MITI) sparked admiration for exceeding its growth targets. In the Eastern bloc, the Soviet Union used centralized planning, state ownership of the means of production, and collectivization to encourage growth, and in communist China, Mao attempted the "Great Leap Forward." Growth became critical to maintaining government services, research programs, and welfare of all kinds. As with the health initiatives of the Great Acceleration, so too with the economic systems of growth. Initially all seemed well, but then the foundations began to crumble as the headwinds of debt, declining natural resources, demographic shifts, and rising inequality ate away at its foundations.

Several factors make continued growth a tenuous if not a dangerous proposition. The mantra of growth continues to be chanted although the global economy has been transformed in at least two critical and related ways: first, the concentration of wealth at the top and the widening gap between rich and poor and, second, the change from the postwar economy that rested on the production and exchange to an economy where most wealth arises in the financial sector. The estimated value of all economic activity in the production and marketing of goods and services in the world today is $105 trillion. The value of financial derivatives betting on changes in these markets is $667 trillion (Copeland 2023; Stevenson 2024; Lanchester 2024). In other words, the biggest business in the world produces nothing physically tangible, although the political and social fallout of this global gambling by the wealthy produces tangible and intangible dangers.

Another way in which the promise of economic growth is dangerous is that nature has limits to how much can be drawn down while it still replenishes itself. For instance, fresh water replenishes itself through rain cycles at the rate of about 1% a year. These limits have not only been reached but exceeded. We overshot the planet's ability to refresh 'blue water' which we drink in 1905; we now use energy-intensive methods to mine 'fossil water' from aquifers deep underground. The boundary for 'green water' available in soils for plants and microorganisms was passed in 1929 (Richardson *et al*. 2023). We exceed Earth's capacity to maintain regenerative cycles in many other sectors as well. In essence, to grow we have been drawing down on the future and continue to do so at a faster and faster rate. This is true especially of the rich, but even the average person in poor countries such as Nicaragua, Indonesia, and Uruguay draws down more of Earth's bounty each year than can be replenished in that year according to the organization Earth Overshoot Day[8]. We gorge on the future through the technosphere, and wallow in the waste products of its unregenerative processes to our cost and that of the entire biosphere. The gifts of the 'economic miracle of infinite growth' resemble a trap for humanity: growth is necessary to maintain the technosphere upon which we depend, and yet growth is also rapidly undermining the habitability of the planet. Those who suffer first are the poorest and least able to protect themselves, human and nonhuman both.

Politics: The rise of democracy is closely related to economic growth. The hopes for self-determination began to take root with an expanding middle class based on a growing mercantile and professional economy, and flowered in the twentieth century with decolonization, women's rights, and the establishment of a host of different types of democracy during that century. The close alliance between economic growth and political liberty has been noted by many. In Dipesh Chakrabarty's telling phrase, the mansion of modern freedoms stand on the ever-expanding base of fossil fuel use. Some scholars correlate the end of serfdom and slavery with the rise of the new, mineral-based sources of energy that could free people from arduous physical labor and provide more ample lives and greater choice (Nikiforuk 2012; Mouhot 2019).

The new technologies (fuels, fertilizers, increased global trade) and the new techniques of governance spurred by these new sources of energy reduced the dangers of local contingencies. People no longer had to depend on what their immediate area could produce by way of water, food, fuel, and shelter which were prone to whims of natural variables, and could seek sustenance from wider ecosystems, some very distant indeed. In short, growth was pursued as a way to limit local precarity and secure predictable (and insurable) futures for a wider and wider range of people. These people could then take part in democratic societies through expanded educational systems, cultural opportunities, and much more. In short, before the Anthropocene, the Earth System was fairly predictable, but local weather, soil fertility, religion, authority, literary production and cocktail hours were all highly unpredictable. During the early phase of the Great Acceleration, this system flipped, transferring unpredictability from the local to the planetary. Today, the Earth System is careening towards (or perhaps has already passed) various tipping points. While in the main, at least for a bit longer, the technosphere pumps out regularly available goods and services to the wealthy, everyone is increasingly subject to the unpredictable (and uninsurable) dangers of rampaging fires, rising waters, drought, heat, pandemic, and social instability that accompanies these planetary uncertainties. This situation stokes anger and distrust.

Given the increasing precarity of global systems (e.g. boats supplying consumer goods stranded in the Panama Canal due to unusual rain patterns), one potential avenue of mitigation is to strength local networks, building resilience through *inefficient*

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[8] https://overshoot.footprintnetwork.org/newsroom/country-overshoot-days/

redundancies that are locally controlled. Efficiency relies on predictability; now that the planetary system is unpredictable, inefficient, overlapping ways of attaining necessities is a safeguard. To embrace local redundancies would be to accept once again the precarity of life, a reasonable step given that the promise of predictability secured through global systems drawing down on future resources endangers us all. To do so would mean attuning ourselves again to the resourcefulness, hard work, and community sharing that once tided people over rough patches. This alternative politics—founded in ecological economics—has a growing base of advocates and scholars (Schor 2010; Dietz and O'Neill 2013; Raworth 2018). If we deem democracy valuable, then a new form of democracy that is no longer reliant on growth needs articulation and adoption—soon. It could be said that although 2024 was a banner year for elections with 65 national contests around the world, it was not a banner year for democracy.

Conclusion

To draw on Charles Dickens, the early Great Acceleration was the best of times and the worst of times. It set in place interlinked systems that benefitted many for a while and which are now rapidly propelling us far beyond planetary boundaries into unpredictable territory. The 'Anthropocene' captures the phenomenon of a dangerous Earth System trajectory propelled by human systems and also encapsulates the mid-20th century measurable signals left in the strata that geologists have discovered. It is a framework for bringing together climate change, biodiversity loss, the technosphere, our bodies, economics, politics and much else. As journalist Andrew Revkin observed, it 'has become the closest thing there is to common shorthand for this turbulent, momentous, unpredictable, hopeless, hopeful time—duration and scope still unknown' (Revkin, 2016). Despite the rejection of the AWG's proposed formalization of the epoch on the Geological Time Scale, the concept remains crucial. As science writer Elizabeth Kolbert maintains, 'the Anthropocene is an indispensable term' (Kolbert 2024). While our fractious species is prone to contentiousness and sometimes even to wilful misunderstandings and cruelty, there is still a silver sliver of hope that we will put aside our squabbles to redefine our notion of progress (*Laudato 'Si*, Chapter 5). Whether that silver sliver is merely an insubstantial moonbeam playing on waves or a lighted pathway is up to us. We must recognize the limits of any particular branch of knowledge and any individual perspective, and join together collectively if we are to meet the perils of the Anthropocene with grace, charity, and courage.

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