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THE RESPONSIBILITY OF GEOLOGISTS IN DEFINING THE ANTHROPOCENE

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ABSTRACT: The Subcommission on Quaternary Stratigraphy (SQS), a constituent body of the International Commission on Stratigraphy (ICS), established the Anthropocene Working Group (AWG) in 2009 to examine the Anthropocene as a potential new formal division of the Geological Time Scale (GTS). In October 2023 the AWG submitted the formal proposal to ICS, which in March 2024 rejected the proposal. Among the humanities and Earth system scientists, only the geologists, more than anyone else, have the cultural and technical tools to be aware of the exceptionality of today's times and to place them in deep time context. For example, dealing with one of the main threats, the climate crisis, few are aware that the speed and scale of anthropogenic release rate of the CO2 are unprecedented during the Cenozoic (last 66 Ma). The rejection of Anthropocene formalization hinders the communication, to the public and to policymakers, of the exceptionality of what physically the Anthropocene is, and of the related catastrophic risks to human civilization. Geologists have a responsibility to inform society about the risks young people will face in the near future, and formalization of the Anthropocene represents an extraordinary opportunity in this respect, that has been missed for now.

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Keywords: Anthropocene, climate crisis, tipping points, geologic analogues, geoethics.

1. INTRODUCTION

In March 2024, the proposal of the International Anthropocene Working Group (AWG), founded in 2009 within the Subcommission on Quaternary Stratigraphy (SQS) to study the suitability of the Anthropocene to be promoted to a formal chronostratigraphic unit of the Geological Timescale, was refused by International Commission on Stratigraphy (ICS) and the International Union of Geological Sciences (IUGS). The statement reads: "Despite its rejection as a formal unit of the Geologic Time Scale, the Anthropocene will nevertheless continue to be used not only by Earth and environmental scientists, but also by social scientists, politicians and economists, as well as by the public at large. It will remain an invaluable descriptor of human impact on the Earth system" (IUGS, 2024).

One of the main obstacles to the acceptance of the Anthropocene as a new epoch is the short duration (ca 72 years) of the time interval from the year 1952 CE, which the AWG choose as the beginning of the Anthropocene. However, the Anthropocene concept of the IUGS is different from the "epoch" concept proposed by Crutzen & Stoermer (2000) and Crutzen (2002). The Anthropocene "event" of those in opposition to the "epoch" relegates the importance of the post-mid-20th transformation to simply the latest of many phases of human influence on the Earth, which dates back to the Pleistocene, at least 50,000 years ago.

The AWG has provided an enormous amount of data to support the Anthropocene as a chronostratigraphic unit, with a clear signature in sediments and ice that is distinct from those of the Holocene epoch. Among scientists dealing with the Anthropocene, only Earth sciences researchers and Earth Systems scientists have the cultural and technical tools to be aware of the exceptionality of the times we are living in within the human enterprise, but also within geologic time spanning tens of millions of years. Consequently, they have a responsibility to inform policymakers and the public about the risks young people will face in near future, and the formalization of the Anthropocene represents an extraordinary opportunity in this respect, that has been missed for now.

2. THE PROPOSAL

When introducing the term Anthropocene, Crutzen & Stoermer (2000) and Crutzen (2002), proposed the beginning of the Industrial Revolution in Europe, with the introduction of Watt-Boulton's steam engine (1788). This technological breakthrough led to changes in greenhouse gas concentrations in the atmosphere through increased burning of coal, later accompanied by oil and natural gas. The resulting geological effects were gradual and varied in time and space, with no single clear isochronous signal in the geological record.

However, the formalization of a new unit must respect the strict rules of the International Stratigraphic Guide published by the International Subcommission on Stratigraphic Classification (ISSC), a constituent body of the ICS operating within the IUGS. A precise global start date in the International Geologic Time Scale (GTS) and a correlative Global Boundary Stratotype Section and

Point (GSSP, often called a “golden spike”), which is used to calibrate the stratigraphical record, are needed.

Afterwards, the community of Earth System science (ESS) researchers identified an array of global and near-synchronous signals at ~1950 CE, reflecting abrupt changes of socio-economic factors and biophysical processes. This process, termed the “Great Acceleration”, was coincident with, and driven by, unprecedented increases in population, energy consumption, industrialisation, pollution and globalisation following the end of World War II (Steffen et al., 2015a).

Between 2020 and 2023, 12 research teams formulated proposals for candidate GSSPs and other reference sections in eight distinct geological environments that cover five continents to define the base of the Anthropocene as a series within the GTS (Waters et al., 2023). Among the 12 candidates, the AWG chose as golden spike a level that separates the summer and autumn sediment layers laid down in 1952 within varved sediments in Crawford Lake, a small meromictic lake occupying a sinkhole in Silurian dolomitic limestones of Ontario, Canada.

There, the primary marker shows a rapid increase in $^{239+240}Pu$ radionuclide concentrations from above-ground nuclear detonations, a signal clearly seen in many of the proposed sites, and tens of secondary markers have been identified (McCarthy et al., 2023, 2025).

The efforts made by AWG to respect the rules imposed by the ISSC, as testified by an enormous corpus of publications (e.g. Zalasiewicz et al., 2019; Head et al., 2023a, 2023b; Waters et al., 2024) - by now the term Anthropocene had been cited in over 145,000 documents [(over 15,000 limiting the research to “article title, abstract, keywords” (https://www.scopus.com/)] - have so far proved useless, and formalisation of the Anthropocene must wait another submission in coming years. In my view, the geologists have missed a great opportunity to master what is within their own competence, delegating to the social and economic disciplines the mastering of the Anthropocene concept. In doing so, they hinder the communication to the public and the policymakers of the exceptionality of what the Anthropocene is physically, and of the attendant multiple crises with related catastrophic risks for human civilization.

3. THE EXCEPTIONALITY OF THE ANTHROPOCENE

Starting with the 20th century, the use of a cheap and high-power density energy - oil - has produced an abrupt planetary change forced by the cumulative and overwhelming impacts of human activities. The immense instantaneous power offered by managing fossil fuels has been compared by Hansen (2009) to the bargain with Mephistopheles, who offered Faustus his present desire (i.e. power) at the cost of future detriment (i.e. climate disruption). Fossil fuels raised living standards in much of the world, by replacing the labour of humans and domestic animals.

Globally, the world we inhabit is built and powered to the level of 87% by fossil fuels (Energy Institute, 2025), and some of their industrial uses are difficult to replace. Analysis of the past evolution of energy sources allows us to infer that the substitution of fossil fuels by renewables may require several generations (Smil, 2017). Since energy demands are increasing, renewables are presently supplementing fossil fuels rather than replacing them, supporting Fressoz's thesis (Fressoz, 2025) that there has never been a transition between energy systems in the past, but rather that different forms of energy are symbiotic.

Consequently, climate breakdown and unprecedented biodiversity loss and the dispersal of novel entities (new substances, new forms of existing substances and modified life forms not previously known to the Earth system) to the environment put humanity at grave risk, and threaten human lives, livelihoods and wellbeing worldwide.

Using the comparatively stable interglacial Holocene as the baseline, nine biophysical systems and processes that are critical for maintaining the stability and resilience of the Earth System have been recognized (Rockström et al., 2009; Steffen et al., 2015b). Seven of nine Planetary Boundaries are now assessed as having been crossed, namely for biosphere integrity, climate change, land use, interference with biogeochemical cycles of nitrogen and phosphorus, novel entities, freshwater change and lastly ocean acidification (Persson et al., 2022; Wang-Erlandsson et al., 2022; Richardson et al., 2023; Stenzel et al., 2025; Kitzmann et al., 2025). The two remaining planetary boundaries that are not transgressed are stratospheric ozone depletion and the increase in atmospheric aerosol loading.

Many components of the Great Acceleration and Planetary Boundaries concepts can be analysed as regards their stratigraphic representation, since the Anthropocene emerged from ESS, but geologists have been able to assess the signals of the present environmental changes captured by sedimentary strata (e.g. Zalasiewicz et al., 2017).

4. TIPPING POINTS

Earth system ‘tipping points’ are critical thresholds when environmental stresses become so severe that large parts of the natural world are unable to maintain their current state, leading to abrupt and/or irreversible changes (e.g. Marten, 2005; Lenton et al., 2008).

Twenty-six Earth system tipping points have been identified from evidence of past changes, observational records and computer models: six in the cryosphere, sixteen in the biosphere, and four in atmospheric and oceanic circulation (Lenton et al., 2019, 2023, 2025).

Global warming is rapidly approaching levels that could trigger individual tipping points in systems that can interact with and destabilise other tipping systems, making tipping cascades possible. As warming approaches and surpasses 2°C this may cause tipping points, once considered low-likelihood, to rapidly become much higher-likelihood events (Abrams et al., 2023).

Lenton et al. (2023) identified five major tipping systems that are already at risk of crossing tipping points at the present level of global warming: the Greenland and West Antarctic ice sheets, warm-water coral reefs, North Atlantic Subpolar Gyre circulation, and permafrost regions. However, considering the “committed warming” due to thermal inertia of the oceans, which take up ca. 90% of the Earth’s energy imbalance (von Schuckmann et al., 2023), global warming continues to rise for long periods after a given increase. Recently, Lee et al. (2025) carried out simulations showing that human-induced perturbations will persist well beyond 2100 for several centuries.

Abrams et al. (2023) have investigated the committed warming associated with the CO_2 equivalent (CO_2-e) for each year for three emission scenarios. The results are that the best-estimate threshold will be passed for one, two, and six climate tipping points by the end of the century for the "pre-commitment transient phase" under RCP2.6. RCP4.5, and RCP8.5 scenarios, respectively [RCP2.6 is a strong mitigation scenario in which radiative forcing peaks at approximately 2.6 W/m^2 before 2100 and then slowly declines; RCP 4.5 is the intermediate stabilization pathways with 4.5 W/m^2 radiative forcing stabilized after 2100; RCP8.5 is the high emissions pathway for which radiative forcing reaches >8.5 W/m^2 by 2100 (Fifth Assessment Report (AR5) from IPCC, 2013)]. But, during the subsequent "commitment transient phase", extra warming will increase the risk of triggering climate tipping points, pushing mean temperatures into the possible tipping threshold range for five, six, and nine climate tipping points under RCP2.6. RCP4.5, and RCP8.5, respectively. Under RCP4.5, the scenario that best matches current national commitments, the gap between committed equilibrium warming and pre-commitment transient temperatures is estimated to be 1.2°C in 2100 (Abrams et al., 2023).

Randers & Goluke (2020) have modelled the development of the global climate system from 1850 to 2500 under different assumptions about the emission of human GHGs, finding that a point-of-no return is already behind us. The self-sustained melting of the permafrost caused by methane release, lower surface albedo caused by Arctic marine ice melting, and higher atmospheric humidity would be triggered by just +0.5°C above the pre-industrial level. In any case, an increase of the global temperature of 1.5°C - as desired by the Paris Agreement and already reached by now - would not be "safe" (e.g. Möller et al., 2024).

This level of warning, including the scientific uncertainty about how close we might be to a tipping point, would require climate governance based on principles of international law, such as precaution, equity and justice, as well as care for future generations. Short-term decisions can have severe, even catastrophic, consequences over extremely long-time horizons, potentially affecting life on Earth for several millennia, and future generations' chances for survival and wellbeing (Lenton et al., 2023, 2025).

5. THE CENOZOIC ANALOGUES

Of the nine planetary boundaries, climate change is of special interest to the Earth scientists, since the shift from Holocene stable conditions during which settled civilization developed could make the planet ungovernable. The planetary boundary for atmospheric CO_2 concentration is set at 350 ppmv and for radiative forcing at 1 Wm^{-2} (Richardson et al., 2023). Currently, the atmospheric CO_2 concentration is ca. 425 ppmv (https://scrippsco2.ucsd.edu/) and the estimated total anthropogenic effective radiative forcing is 2.91 Wm^{-2} [2022 estimate, relative to 1750 (Forster et al., 2023)].

Geologic analogues from past climate events are invaluable in understanding the impact of massive carbon release on the Earth system. Since 66 Ma, the Cenozoic era, Earth's climate system has experienced continuous changes, but the global climate trend has been one of cooling (Zachos et al., 2001), while atmospheric CO_2 concentrations have declined overall (Pagani et al., 2005). High-frequency changes in climate have been driven by periodic oscillations in Earth's orbital parameters of eccentricity, obliquity, and precession that affect the distribution and amount of incident solar energy. By contrast, gradual changes in Earth's major boundary conditions were controlled by plate tectonics, with North Atlantic rift volcanism, opening of the Tasmanian and Drake Antarctic gateways, collision of India with Asia and subsequent uplift of the Himalayas and Tibetan Plateau, and the uplift of Panama and closure of the Central American Seaway.

In the Cenozoic time interval, a prominent climatic aberration is the Paleocene-Eocene Thermal Maximum (PETM), which occurred at ca. 56 Ma near the Paleocene/Eocene (P/E) boundary, accompanied by a major perturbation in the global carbon cycle as inferred from carbon isotope data. More than 10,000 petagrams of isotopically heavy carbon were released from volcanism associated with the North Atlantic Igneous Province (Gutjiar et al., 2017).

Sea surface temperatures as constrained by planktonic isotope records increased by as much as 8°C at high latitudes in less than 10 ka. The carbon release to the atmosphere occurred at a rate of 0.6-1.1 Pg C a^{-1}, the record high during the past 66 million years. The initial carbon release during the PETM onset occurred over 4,000 to 6,000 years (Zeebe et al., 2016; Li et al., 2022). Presently, anthropogenic carbon release rates are ca. 11 Pg C a^{-1}, one order of magnitude higher than inferred for the PETM. Therefore, the anthropogenic release rate is unprecedented during the Cenozoic, and this represents a fundamental challenge to constraining future climate projections.

Climate simulations performed by Earth system models have shown that under very high greenhouse gas (GHG) emissions scenario, the Eocene emerges as the most likely analogue, accelerating after 2050 and representing the future climate by 2140 CE. An Eocene-like climate emergence would suggest that the unmitigated warming of the RCP8.5 scenario is approximately equivalent to reversing a 50-Ma cooling trend in two centuries (Burke et al., 2018).

Under the RCP4.5 scenario, characterized by moderate emissions mitigation, the Pliocene emerges as the most common best analogue and climate stabilizes at Pliocene-like conditions by 2040 CE. Pliocene-like and Eocene-like climates emerge first in continental interiors and then expand outwards (Burke et al., 2018).

In the IPCC Sixth Assessment Report (AR6) (IPCC, 2021) the RCP scenarios have been substituted by a new range of scenarios based on Shared Socioeconomic Pathways (SSPs; O'Neill et al., 2016). The set of SSPs recognizes that global radiative forcing levels can be achieved by different pathways of CO_2, non-CO_2 greenhouse gases, aerosols and land use; the set of SSPs therefore establishes a matrix of global forcing levels and socio-economic narratives (IPCC, 2021). Since the RCPs are labelled by the level of radiative forcing they reach in 2100, they can in principle be related to the SSPs scenarios. In this sense, the RCP4.5 roughly corresponds to middle-of-the-road SSP2-4.5 (IPCC, 2021, Fig. 1.28), but they are not directly comparable. Although in AR6, the high-end scenarios RCP8.5 or SSP5-8.5 have been argued to be implausible to unfold, these low-likelihood but high-impact scenarios must be considered, given the stake.

The Mid-Pliocene (3.3-3.0 My), also known as the

Piacenzian warm period, remains the best palaeoclimate for understanding the workings of the Earth system at ca. 400 ppmv (360-420 ppmv) concentrations of CO_2 (Burke et al., 2018; IPCC, 2021). Therefore, the Pliocene is the most appropriate analogue at 400 ppmv, since today we are at ca. 425 ppmv, although the ongoing increase in atmospheric CO_2 concentration makes the Miocene Climatic Optimum (ca. 16.9-14.7 My, ca. 400-600 ppmv of CO_2) a strong candidate to serve as a future climate analogue (Steinthorsdottir et al., 2021). In the Mid-Pliocene, mean annual surface temperatures were approximately 1.8 °C to 3.6 °C higher than preindustrial temperatures, the ice sheet extents were reduced, and sea level was about 16 m higher than today (Burke et al., 2018; Dumitru et al., 2019). The AR6 sets as very likely (90-100% probability) a global mean sea level (GMSL) 5-25 m higher than today and temperatures 2.5°C-4°C warmer (IPCC, 2021). Therefore, sea level and temperature rises are both committed, unless implausibly large volcanic eruptions injecting aerosols into Earth's stratosphere will last for decades.

6. DISCUSSION

The main criticisms to the proposal of the Anthropocene as formal unit in the GTS is that 72 years is too short to recognize an epoch, and that the future is not geologic time. Apart the identification of a potential GSSP at the Crawford Lake, time is precisely the variable that makes the formalization of the Anthropocene an urgent and invaluable issue. The global changes of the Earth system produced by *Homo sapiens* - though mainly by Western societies - in less than a century are so profound that they pose some of the gravest threats faced by humanity. For example, dealing with one of the main threats, the climate crisis, the anthropogenic release rate of the CO_2 is unprecedented during the Cenozoic (last 66 Ma). Such an exceptional event may be fully understood in its planetary context only by Earth scientists.

During the Phanerozoic (last 538 Ma) our planet has suffered five main extinction episodes, and several minor extinctions, always accompanied by climate crises, fostering the evolution of living organisms including our species. However, the rise of what we call civilization benefitted from the stable conditions of the mid-Holocene (the last 10^3 years), when climate and global mean sea level remained nearly constant. Therefore, what is presently at risk is human civilisation, not the life itself or the planet.

Regarding the criticism regarding the inherently future scope of the Anthropocene, it must be remembered that although the Anthropocene is, so far, of extremely short duration, the Anthropocene changes are already affecting the sedimentological and stratigraphic record, leaving a distinctively transformed fossil record that will persist long into the future. The climate system is already a mayor element of the proposed new epoch, and future projection is a standard part of science (Summerhayes et al., 2024).

The long timescale of the temperature responses to anthropogenic forcing, with the committed warming in the pipeline, is a consequence of the ocean's great thermal inertia (Hansen et al., 2023). The climate system's slow response allows the possibility to avoid the "point of no return". The delayed response provides humanity time to mitigate the anthropogenic climate forcing so that the equilibrium warming - or even the 100-year warming, the time in which 60% of the equilibrium warming is achieved - may never occur (Hansen et al., 2025). However, the time for action is now, not tomorrow.

Among natural scientists, Earth scientists and particularly geologists are the only ones who have constant awareness of the deep time dimension. Not surprisingly therefore, the setting of global standards for expressing the history of the Earth by means of the units (periods, epochs and age) of the GTS is the responsibility of geologists. But, after all, the geological division of time is a human construction subjected to continuous refinements. In the recent past, geologists did not disdain to strongly quarrel over the GTS, the last time about the use of the name Quaternary (Kerr, 2008). The designation of the Holocene epoch itself may be questioned, since it is based on a climatic definition, being just one more interglacial period in a long series started 2.6 Ma ago (Lewis & Maslin, 2015).

However, the Anthropocene is not only an academic issue, because its consequences are an existential threat to civilization and the designation of the Anthropocene in general as an "invaluable descriptor of human impact on the Earth system" (IUGS, 2024) confuses the specific meaning of the Anthropocene as proposed by Crutzen and worked on by the AWG.

7. CONCLUSIONS

The decision to reject the formalization of the Anthropocene, which must await a re-submission, has temporally delegated to social and humanity scientists the managing of this concept. In this way, its link to the dimension of deep time, the prerogative of the geologists, is likely to be lost, along with the challenge of systemic risk governance. The long delay of climate in achieving its equilibrium response is both a curse and a blessing, because a great amount of future warming may be built up before actions required to stem climate change are undertaken. In addition, scientific uncertainty about how close we might be to a tipping point should be reason for urgent action, not delay.

The full assumption of responsibility allowed by formalization of the Anthropocene by geologists would have greatly informed policymakers of the critical moment we are living through in human history. The ethical obligation of modern geoscientists includes the transfer of knowledge to society, not only to the scientific community (Bobrowsky et al., 2018). The extremely high stakes involved place a major burden of responsibility on the present generations and dramatically elevate the need for a precautionary approach, also to avoid intergenerational injustice towards young people and their descendants. The nature of the threats presented by tipping dynamics in the Earth system challenges the common linear logic of decision-making in global governance. Short-term decisions, that is actions and inaction over the next 10 years, can have ripple effects over millennia.

Policymakers must consider their responsibility for future impacts that only they can prevent, but they must urgently be informed and pressed by geologists. It is desirable that the SQS and/or the ICS review the Anthropocene soon.

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Declaration of Competing Interest

The author declare that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

No data was used for the research described in the article.

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