The Anthropocene: comparing its meaning in geology (chronostratigraphy) with conceptual approaches arising in other disciplines

Jan Zalasiewicz[1], Colin N. Waters[1], Erle C. Ellis[2], Martin J. Head[3], Davor Vidas[4], Will Steffen[5], Julia Adeney Thomas[6], Eva Horn[7], Colin P. Summerhayes[8], Reinhold Leinfelder[9], J. R. McNeill[10], Agnieszka Gałuszka[11], Mark Williams[1], Anthony D. Barnosky[12], Daniel deB. Richter[13], Philip L. Gibbard[8], Jaia Syvitski[14], Catherine Jeandel[15], Alejandro Cearreta[16], Andrew B. Cundy[17], Ian J. Fairchild[18], Neil L. Rose[19], Juliana A. Ivar do Sul[20], William Shotyk[21], Simon Turner[19], Michael Wagreich[22], and Jens Zinke[1]

[1]Geography, Geology and the Environment, University of Leicester, Leicester, UK, [2]Geography & Environmental Systems, University of Maryland, Baltimore, Maryland, USA, [3]Earth Sciences, Brock University, St. Catharines, Ontario, Canada, [4]The Fridtjof Nansen Institute, Lysaker, Norway, [5]The Australian National University, Canberra, Australia, [6]History, University of Notre Dame, South Bend, Indiana, USA, [7]German Studies, University of Vienna, Vienna, Austria, [8]Scott Polar Research Institute, University of Cambridge, Cambridge, UK, [9]Geological Sciences, Freie Universität, Berlin, Germany, [10]Georgetown University, Washington DC, USA, [11]Institute of Chemistry, Jan Kochanowski University, Kielce, Poland, [12]Jasper Ridge Biological Preserve, Stanford University, Stanford, California, USA, [13]Nicholas School of the Environment, Duke University, Durham, North Carolina, USA,[14]Institute of Arctic and Alpine Research, University of Colorado, Boulder, Colorado, USA, [15]LEGOS, Université de Toulouse, CNES, CNRS, IRD, Toulouse, France, [16]Geología, Facultad de Ciencia y Tecnología, Universidad del País Vasco UPV/EHU, Bilbao, Spain, [17]School of Ocean and Earth Science, National Oceanography Centre, University of Southampton, Southampton, UK, [18]School of Geography, Earth and Environmental Sciences, University of Birmingham, Birmingham, UK, [19]Geography, University College London, London, UK, [20]Leibniz Institute for Baltic Sea Research Warnemüende (IOW), Rostock, Germany, [21]Renewable Resources, University of Alberta, Edmonton, Alberta, Canada, [22]Geology, University of Vienna, Vienna, Austria

Corresponding author:
J. Zalasiewicz, jaz1@leicester.ac.uk

Key points:

- The Anthropocene concept developed in the Earth System science community is closely consistent with its proposed chronostratigraphic (geological) definition.

- A wide range of other meanings of the Anthropocene subsequently emerged that represent inherently valid, but partly different, concepts.

- Cross-disciplinary discussion is encouraged to help resolve issues of meaning and communication in this important area.

Abstract The *term* Anthropocene initially emerged from the Earth System science (ESS) community in the early 2000s, denoting a *concept* that the Holocene Epoch has terminated as a consequence of human activities. First associated with the onset of the Industrial Revolution, it then more clearly focused on the Great Acceleration in industrialization and globalization in the 1950s that fundamentally modified physical, chemical and biological signals in geological archives. Since 2009, the Anthropocene has been evaluated by the Anthropocene Working Group (AWG), tasked with examining it for potential inclusion in the Geological Time Scale. Such inclusion requires a precisely defined chronostratigraphic and geochronological unit with a globally synchronous base and inception, with the mid-20th century being geologically optimal. This reflects an Earth System state in which human activities have become predominant drivers of modifications to the stratigraphic record, making it clearly distinct from the Holocene. However, more recently, the term 'Anthropocene' has also become used for different conceptual interpretations in diverse scholarly fields, including the environmental and social sciences and humanities. These are often flexibly interpreted, commonly without reference to the geological record, and diachronous in time; they often extend much further back in time than the mid-20th century. These broader conceptualizations encompass wide ranges and levels of human impacts and interactions with the environment. Here, we clarify what the Anthropocene is in geological terms and compare the proposed geological (chronostratigraphic) definition with some of these broader interpretations and applications of the term 'Anthropocene', showing both their overlaps and differences.

Keywords Anthropocene, chronostratigraphy, Earth System science, humanities, social sciences

1. Introduction

The term Anthropocene was coined by Paul Crutzen in 2000 (Crutzen & Stoermer, 2000; Crutzen, 2002) during a review of the first decade of research in the International Geosphere-Biosphere Programme (IGBP). The term crystallized the growing realization in the Earth System science (ESS) community that human activities were fundamentally changing the Earth System (Steffen et al., 2020). The ESS focus on planetary processes, including significant global changes to the atmosphere, biosphere, cryosphere, geosphere, hydrosphere, pedosphere, technosphere and the climate, demonstrated that conditions typical of the Holocene (specifically, the last 11,700 years of Earth history) no longer resembled those of the present day. In proposing this new term, Crutzen and Stoermer (2000, p. 17) indicated the onset of the Anthropocene as "*the latter part of the 18th century... when data retrieved from glacial ice cores show the beginning of a growth in the atmospheric concentrations of several 'greenhouse gases', in particular* CO_2 *and* CH_4". They, and Crutzen (2002), linked this physical record with the global effects of human activities associated with the onset of the Industrial Revolution in the UK, catalyzed by the development of a greatly improved steam engine by James Watt.

Continued research within the IGBP community led to the recognition that there were sharp upward inflections of many socio-economic and resultant Earth System trends of global significance in the mid-20th century. The term for this, the 'Great Acceleration', was coined in a Dahlem Conference in 2005 that included social scientists and humanities scholars in addition to natural scientists. This explosive growth of the human enterprise from the mid-20th century had earlier been described from a historical context (McNeill, 2001), providing insights that shifted the emphasis in Anthropocene research from the Industrial Revolution to the Great Acceleration. The major outcomes of the Dahlem Conference were published by Steffen, Crutzen and McNeill (2007), proposing the Great Acceleration as a 'second stage' of the Anthropocene, following the Industrial Revolution. The Great Acceleration has parallels with Karl Polanyi's 1944 book '*The Great Transformation*' which provided a holistic view of modern market societies. In a similar way, the Great Acceleration aims to express the holistic, comprehensive and interlinked nature of post-1950 changes covering socio-economic factors and biophysical processes. This shows an exemplar of ways in which ideas and terms move between disciplines, as is true for the Anthropocene.

The geological community first addressed the Anthropocene context in a preliminary analysis by the Stratigraphy Commission of the Geological Society of London (Zalasiewicz et al., 2008). As a national body it had no power to formalize the term. However, they concluded that there was geological evidence to support formalization and in 2009 the Anthropocene Working Group (AWG) was established (see SQS, 2009). The AWG is a task group of the Subcommission on Quaternary Stratigraphy (SQS), a component body of the International Commission on Stratigraphy (ICS) that is responsible for maintaining and refining the International Chronostratigraphic Chart, which serves as the basis for the Geological Time Scale (GTS). A fundamental quality of all chronostratigraphic units incorporated within this chart is that each is defined by an isochronous base, representing a conceptual surface of *identical time* around the globe. This surface is recognized ('correlated') in practice, with varying degrees of precision, by stratigraphic signals within sedimentary deposits and other geological materials, and its definition is fixed by a designated marker at a unique reference section known as a Global Boundary Stratotype Section and Point (GSSP), commonly termed a 'golden spike' (Salvador, 1994).

The AWG grew and evolved with international membership (as of late 2020 from 14 countries). Geoscientists make up most of the current membership of 38. However, given that the AWG considers human phenomena and timescales as well as geological processes, it includes representatives beyond, but for the purposes of the AWG work complementary to, the geological sciences – archaeology, ESS, ecology, geography, oceanography, history, philosophy, and international law. These members work on human impacts on the environment and their consequences, exploring the utility of the formalization of the Anthropocene on the GTS for the development of science and scholarship, extending well beyond Earth science.

The AWG has analyzed a wide range of aspects of the Anthropocene concept, with the broad range of evidence being summarized by Zalasiewicz et al. (2019a). However, the AWG's primary task is to assess the Anthropocene as a potential geological time (chronostratigraphic) unit, following the elaborate protocols stipulated by ICS and its parent body, the International Union of Geological Sciences (IUGS). The AWG is therefore progressing towards a proposal for a formal definition of the chronostratigraphic Anthropocene, and has agreed that its isochronous base would be defined by stratigraphic signals associated with the Great Acceleration of the mid-20th century (AWG, 2019).

There has, however, been a growing development of alternative and quite different understandings of the Anthropocene by both a small minority of AWG members and among several disciplines outside geology ranging from the natural and social sciences to the arts and humanities (see Ellis, 2018; Horn & Bergthaller, 2020; Thomas et al., 2020). The origin of these alternative understandings may stem back to the title of the Crutzen (2002) publication – "Geology of Mankind" and the by-line often used when referring to the Anthropocene, as "the human age" (e.g. Braje, 2015; Monastersky, 2015) or "Age of Humans" (Waters, 2016). This has led many to use the term Anthropocene to encompass the concept of *all* discernable human impact on the planet—a much broader concept than Crutzen originally intended. In this broader view, the Anthropocene's origin is diachronous, i.e. time-transgressive, and varies regionally, towards the time when *Homo sapiens* first gained collective capacities to change Earth's ecology in unprecedented ways. The selection of key events when human societies first began to play a significant role in shaping the planet commonly reflects different disciplinary perspectives. For example, anthropologists and archaeologists may consider the development of the first urban communities, or development of agriculture expressed in either the sedimentary record as changing pollen records or inferred from modified atmospheric compositions. In contrast, as a geological task group in stratigraphy, the AWG investigates the Anthropocene in accordance with the mandate given to it by the SQS, as a potential geological time unit during which "*human modification of natural systems has become predominant*" (SQS, 2009), rather than locally or regionally significant.

This paper explores the diverse, but often overlapping, understandings of these "anthropocenes" and contemplates whether there is scope for such diverse meanings for the same term to coexist across disciplines, and how formally defining the Anthropocene as an epoch (in the geological sense) using the standard chronostratigraphic approach could contribute to and facilitate cross-disciplinary understanding.

2. The Anthropocene as a potential new division of the Geological Time Scale

The Anthropocene from a geological perspective would be, if formalized, like all the other units of the GTS, both a unit of 'abstract time' (of geochronology) and a material unit of strata (and hence of chronostratigraphy) – see Salvador (1994). *Chronostratigraphy* is the branch of stratigraphy concerned with the application of time to rock successions. A *chronostratigraphical* division refers to a succession deposited in a particular time interval. These divisions are hierarchical, with series being of higher rank than stage, but lower than system. Corresponding *geochronological* divisions represent 'abstract' time intervals, with epoch being of equivalent rank to series. Chronostratigraphic units, and hence the geochronological counterparts, are defined in most circumstances by a specific point at a specific level within a stratotype section, the Global Boundary Stratotype Section and Point.

The proposed Anthropocene Epoch comprises time and the events that took place during its span, whereas the corresponding Anthropocene Series comprises all the geological deposits laid down over that time interval. Geological deposits are typically considered as layers of rock or sediment, although in recent decades 'classical' conceptions of rock have been extended. For instance, the base of the Holocene Series (Walker et al., 2009) and of the Greenlandian and Northgrippian stages of the Holocene (Walker et al., 2018) have been defined in ice cores, whilst the base of the Meghalayan Stage of the Holocene is in a speleothem (Walker et al., 2018). Before human-recorded history began, such geological materials are the only source of evidence for Earth history through the physical, chemical and biological clues that they contain. This evidence has continued to accumulate, and so the geological record of the Anthropocene is crucial to establishing the scale, nature and rates of modern processes by comparison with those earlier in Earth history: it is the direct link to Earth's deep time record. The geological record has been fundamental to ESS by providing evidence for past states and trajectories of, and clues to the forcing mechanisms that have driven changes to, the Earth System.

The synchroneity and precision of definition of both epoch and series (by GSSP) is essential to geoscientists, as the boundary then acts as a time reference surface, around which (commonly complex and diachronous) events and processes in different parts of the world can be located and ordered in time and space, in order to construct a meaningful Earth history. Zalasiewicz et al. (2019a, Chapter 1.3) provide examples of GSSPs in the ancient geological record that bear useful comparison with the Anthropocene. Any unit of the GTS, hence, is meant to be precisely and unambiguously understood worldwide. Changes to the GTS are made only following careful scrutiny: the system is conservative by design in order to maintain coherence with the earlier literature. The approach to recognizing a potential GSSP for the Anthropocene has been outlined by Waters et al. (2018) and current assessment is being undertaken on a number of sites across the planet in diverse environments of sedimentary deposition. Once a particular site has been recommended by the AWG to serve as the GSSP, it must pass three additional levels of international scrutiny, by a 60% supermajority vote successively within the SQS, ICS and IUGS, before the unit it defines can be incorporated officially into the GTS (Head, 2019). For better tracing of such a formalized boundary across the globe, a GSSP is often accompanied by designated auxiliary sections depicting the lower boundary across a spectrum of depositional settings, a practice which will also be followed by the AWG (see Waters et al., 2018). Only the GSSP, however, is formally designated.

Anthropocene strata within this chronostratigraphic framework comprise all those deposited within the precisely defined time interval, whether they are: anthropogenic such as the ‘artificial ground’ beneath cities; partly ‘natural’ but within anthropogenic contexts, such as lake deposits formed behind large dams; natural sediment accumulations that include anthropogenic traces such as microplastics or artificial radionuclides; or fully ‘natural’ sediments/rocks with few or no such indicators.

2.1 Distinguishing ‘anthropogenic’ from Anthropocene

It is important here to distinguish “anthropogenic” from Anthropocene. While anthropogenic deposits may commonly range to older levels of the Holocene or even Pleistocene, especially in terrestrial settings, the base of the Anthropocene as a chronostratigraphic unit is recognizable only by anthropogenic indicators in the stratigraphic record that are nearly globally synchronous. Evidence of global synchronicity is determined by appropriate age indicators such as radiometric dating (e.g. ^{137}Cs, ^{210}Pb, ^{14}C), artefacts, specific persistent organic pollutants, modern plastic polymers, industrially sourced fly-ash, bomb-sourced radionuclides or the preserved remains of invasive species introduced by human activity (Waters et al., 2016, 2018; Zalasiewicz et al., 2019a).

Seemingly counter-intuitively, despite human modification of the planet being most clearly expressed in artificial deposits associated with the archaeosphere, no candidate GSSP is currently being investigated in such deposits, despite their richness in anthropogenic evidence (Edgeworth et al., 2019), because of their typically punctuated, patchy and locally disturbed accumulation. In contrast, ‘natural’ successions in some marine, lake and estuarine sediments, glacial ice, corals, and speleothems may continuously record human-driven environmental change to annual or sub-annual resolution over centuries and even millennia (Waters et al., 2018). Nonetheless, one site being analyzed is within an anthropogenically defined setting (an artificially dammed reservoir) and a GSSP could be located in wholly anthropogenic deposits, if a suitable candidate site showing sufficiently continuous sedimentation and appropriate stratigraphical signals were to be found and proposed.

The Anthropocene in its geological (that is, chronostratigraphic / geochronological) sense encompasses *all* events and processes on Earth during its span, whether human or natural. Thus, it encompasses volcanic eruptions, earthquakes, the passage of ocean currents and changes of climate, as well as human social and economic activities, many of which now impact substantially on climate, landscape, ocean, biosphere and geosphere. Precisely defining its beginning provides a systematic time framework into which the many other, commonly time-transgressive geological units (e.g. those based on rock types and fossils) can be integrated and analyzed. And, it allows consistent comparison of rates of change of different Earth processes with those of other time intervals, not least quantitatively (e.g. Syvitski et al., 2020)

For instance, in the ~70 years of the chronostratigraphic Anthropocene up to 2015, the amount of Earth surface rock and sediment moved and reshaped by human mineral/rock extraction and construction activities was some 6.4 trillion tonnes, 30-fold larger than during the previous 70 years (Cooper et al., 2018). This is some seven times greater than the mass of sediment carried by the Earth's rivers to the ocean, and about two orders of magnitude greater than the total mass of magma erupted by the world's volcanoes (http://volcano.oregonstate.edu/eruption-rates) over that time. Humans have modified ground progressively across much of the Holocene, as agriculture and urbanization developed. However, the rate of production and consequently the vertical growth and lateral spread of these anthropogenic deposits (or archaeosphere) has increased greatly during the chronostratigraphic Anthropocene (i.e., since the early-1950s) to a point where human modification of the planet's surface has become overwhelmingly dominant over non-human natural processes.

The energy to drive these landscape changes was largely derived from the burning of fossil fuels and, as a direct consequence, atmospheric CO_2 levels increased by >104 ppm in 70 years since the mid-20th century. This exceeds the 80 ppm rise over a ~6000-year interval during the last glacial–interglacial transition and has taken place >100 times more rapidly (see Waters et al., 2016, fig. 5). This largely reflects the striking increase in fossil fuel consumption in the chronostratigraphic Anthropocene, approaching 90% of all coal, oil and gas used to date: in that brief interval, the total human-appropriated energy use of all kinds exceeded that in *all* previous human history (Syvitski et al., 2020).

These kinds of systematic comparisons, like those made across many of the Earth's geological time intervals, are facilitated by the precise definition of such intervals. For example, current and future climate forcing scenarios can be compared with geological precedents over the last 420 million years (Foster et al., 2017; see also Burke et al., 2018). Treating the Anthropocene in this way allows its processes (both human and non-human) to be placed within a context of planetary space and deep time. The Anthropocene here – like the current formal units of the GTS – forms part of a practical time framework within which all geologically significant phenomena in Earth's history can be ordered.

The brevity so far of the Anthropocene compared with other geological time intervals, the novel nature of many of the human-generated stratigraphic signals (such as technofossils, i.e. fossilizable human artefacts, commonly made of novel materials such as plastics) and the linking of geological consequences to societal actions (and therefore involving a political dimension), have been factors behind criticism of the Anthropocene as a potential formal geological time term from within the geological community (e.g. Finney & Edwards, 2016). While such criticisms may be reasonably answered (Zalasiewicz et al., 2017; Head, 2019), they nevertheless are an indication of the challenge, perhaps less technical than cultural within geology, of considering, in a formal geological context, the unprecedented change in the scale, rate and nature of human planetary forcing associated with the 'Great Acceleration'. The currently short duration of the proposed Anthropocene does not itself contravene requirements for inclusion of a unit in the time scale, and indeed follows a trend: the most recent intervals of geological time: the Cenozoic Era (66 Ma), the Quaternary Period (2.6 Ma), and the Holocene Epoch (11,700 years b2k) along with its constituent stages (of 3465–4270 years), all have the briefest durations within their rank in the GTS.

The phenomena of the Anthropocene are important *per se*, irrespective of their cause. One may consider just a few of these (see Waters et al., 2016; Syvitski et al., 2020): 1) the rapid post-industrial increase in atmospheric CO_2 by over a third; 2) the doubling of the surface N and P cycles; 3) the more than order-of-magnitude increases in the diversity of mineral-like substances and in terrestrial erosion/sedimentation rates; and 4) the marked accelerations in biological invasion (Seebens et al., 2017, 2018) and extinction rates (Ceballos et al., 2015). If these phenomena were due to some drastic natural forcing, such as a bolide impact, they would equally well provide justification for a distinctive new geological epoch. Indeed, in such a case the recognition and definition of this geological time unit, without the baggage of responsibility carried by our own species, would likely be considerably more straightforward. Nonetheless, it is an important feature of the geological meaning of the Anthropocene in that it refers to the *manifestation* of human effects: the *consequence* in strata.

Similarly, if the current direct anthropogenic drivers are joined or subsumed by a cascade of 'natural' Earth System drivers arising from positive feedbacks induced by anthropogenic forcing, such as methane (CH_4) expulsion from melting permafrost, or CO_2 expulsion from warming oceans, then this process could still be regarded as forming part of the same phase of Earth history. As comparison, the Eocene Earth System was triggered by, but not restricted to, the short-lived but consequential Paleocene–Eocene Thermal Maximum event (Zachos et al., 2008). The anthropogenic forcings we now associate with the chronostratigraphic Anthropocene will have an effect far into the future, to set a pattern of Earth System evolution that may long outlast humans.

3. The Anthropocene from an Earth System science perspective, as a new state of the Earth System

As indicated above, the concept of the Anthropocene was born in the ESS community, itself a relatively new development in the natural science research arena. Building on the work of such pioneers as Vladimir Vernadsky (Grinevald, 2007) and James Lovelock (Lovelock, 1979), the thrust of ESS is far more integrative and trans-disciplinary than occurs in most areas of academia. ESS operates on the premise that "*the Earth System behaves as a single, self-regulating system comprised of physical, chemical, biological and human components, with complex interactions and feedbacks between the component parts*" (Steffen et al., 2004, p. 298). The Earth System is defined as having an outer spatial boundary at the top of the atmosphere but a rather fuzzy lower boundary depending on the timescales of interest (Lenton, 2016).

The interaction between the nascent ESS community and the well-established field of geology was pivotal from the very beginning of ESS. For example, the IGY (International Geophysical Year) in 1957–1958 brought together scientists from 67 countries to study the geosphere in a highly integrated way, creating a step-change in our understanding of meteorology, oceanography and glaciology – all central to understanding the Earth System as a whole (Beynon, 1970). Nevertheless, the IGY largely ignored biology, which was finally integrated with other disciplines during the International Geosphere-Biosphere Programme (IGBP), beginning in 1986, and during the International Polar Year of 2007–2009 (Summerhayes, 2008). The links between ESS and stratigraphy have been particularly important, with the continuous stratigraphic record, as embodied in the GTS, providing insights into the evolution and dynamics of the Earth System throughout its 4.54 billion year history (Steffen et al., 2016).

The stage for the Anthropocene concept was set by the detailed record of Earth System dynamics through the Holocene, based on the multitude of stratigraphic data synthesized by IGBP's PAGES (Past Global Changes) core project. PAGES supports research on the Earth's past climate and environment to obtain better predictions of future trends. In fact, Paul Crutzen, in proposing the Anthropocene, was reacting to a presentation of PAGES research at the annual meeting of the IGBP Scientific Committee, held on 22–25 February 2000 in Cuernavaca, Mexico; Crutzen interrupted the presentation by forcefully asserting that the Earth System was no longer in the Holocene. Thus, in addition to introducing the term 'Anthropocene' to the ESS community, Crutzen made the connection between the GTS and, in some cases, state changes in the Earth System, changes in this case clearly driven by human action.

The Anthropocene was quickly adopted by the IGBP as the primary organizing principle when it restructured for its second decade of research in the early 2000s (e.g., Steffen et al., 2004). Projects were organized around the land, ocean, and atmosphere, as well as a strong focus on the interactions between them (e.g., land–ocean). The core of the effort was built around PAGES and AIMES (Analysis, Integration and Modeling of the Earth System; Schimel et al., 2015), which integrated the work of the individual projects as well as being linked to the World Climate Research Programme, the International Human Dimensions Programme, and Diversitas, a biodiversity-oriented program. The strategy was to build a coherent research effort along a timeline from the geological past through the present and into the future. The overall aim was to understand the changing dynamics of the Earth System as a whole, and in particular the state change in the system that was unfolding as a result of the broad range of human pressures.

As the concept of the Anthropocene became more widely adopted in the ESS community, the focus shifted away from an earlier model of progressive change from Holocene to Anthropocene to that of a clear, rapid transition in the state of the Earth System. This transition occurred in the mid-20th century, albeit with many earlier human-driven changes to components of the Earth System that as a whole remained within the envelope of the Holocene. The transition away from a well-defined Holocene state of the Earth System, as embodied in the Great Acceleration, is thus consistent with the definition of the Anthropocene from a geological, chronostratigraphic perspective (Steffen et al., 2016). Where the Earth System trajectory is headed in the Anthropocene is an open question. The Anthropocene is currently characterized by an exceptionally rapid rate of change of the Earth System (Syvitski et al., 2020), whose ultimate state is yet to be determined by a combination of human actions and Earth System responses (Steffen et al., 2018; Lenton et al., 2019).

4. The Anthropocene and conceptual approaches emerging in some other disciplines

Following the origin and initial use of the Anthropocene in ESS since the early-2000s and the beginning of its geological analysis as a potential addition to the GTS since 2009, the Anthropocene began to be used by a much wider range of academic communities, notably within the humanities and social and environmental sciences, including anthropology, archaeology, history, geography, sociology, philosophy, and international law (for overviews see Conversi, 2020; Horn & Bergthaller, 2020; Thomas et al., 2020). In some of those disciplines, and in part of the literature, understanding of the Anthropocene concept has diverged widely from the ESS and geological (chronostratigraphic) concepts. According to some views, they reflect to varying degrees the notion that the scientific approach might be overly narrow and restrictive, and that the perspectives and insights of the humanities and social sciences should be at the forefront of analysis; it has been argued in that connection that characterizing the Anthropocene scientifically using purely quantitative data needs to be complemented by an understanding of how it captures “*human interaction, culture, institutions, and societies – indeed, the meaning of being human*” (Palsson et al., 2013, p. 10). While this may seem to contrast with the temporal, evidence-based, and planetary approach followed by the geological and ESS communities, there is clear overlap between these two spheres of endeavor, and analyses of Earth System behavior in the Anthropocene can closely engage with socio-technological aspects of the world (e.g. Haff, 2014a, 2014b, 2016, 2017; Leinfelder, 2017).

However, as also discussed by Conversi (2020, pp. 3–4), there are many other fields within the social sciences and humanities, such as those concerned with inter-State relations, including international law and geopolitics, where a stricter geological understanding is referenced – and some scholars within these communities have adopted and used the term consistent with its ESS/ chronostratigraphic meaning (e.g., Chakrabarty, 2009; Vidas, 2011; Thomas, 2014; Vidas et al., 2015a; Latour, 2017; Renn, 2020) while exploring the human drivers and consequences. Others have adapted it, modifying the meaning by focusing on the 'anthropos' element in the term, and commonly using it to emphasize that significant human influence on the Earth's environment long predates industrialization (Bauer & Ellis, 2018). The debate then centers on *when* the Earth System became radically altered through anthropogenic impacts, with the timing not necessarily constrained to an isochronous beginning as required for a geological (chronostratigraphic) Anthropocene.

Examples of the use and understanding of the term 'Anthropocene' in different disciplines are summarized in Table 1.

5. The Early Anthropocene Concept

5.1 Anthropocene in anthropology, archaeology, and pedology

Many anthropologists and archaeologists consider that the Anthropocene began thousands of years ago, based on differing criteria that typically require a diachronous onset. Smith & Zeder (2013) emphasized key human innovations such as crop domestication representing 'environmental engineering' or 'niche construction', which for these authors makes the Anthropocene essentially coeval and synonymous with the Holocene. Their interpretation, though, emphasizes the early *cause* (inception of this novel form of human interaction) over the stratigraphic *effect* (consequence) or the magnitude of planetary alteration, and hence reworks the Anthropocene according to archaeological/ anthropological criteria, rather than chronostratigraphic (geological) ones in which the correlation potential of stratigraphic signals is key to defining a time unit. However, a direct *causal link* between today's stratigraphic effects attributed to the Anthropocene and such early 'causes' is difficult to establish, since these human activities are distant precursors of the larger transformations at much later stages of the development of human societies.

The soil scientists Certini & Scalenghe (2011) proposed that anthropogenic soils as old as 2000 BP mark the beginning of the Anthropocene, for human-altered soils mark a substantial global impact of humans on the total environment, and by 2000 BP civilization's effects on soils were extensive. From local to regional scales, soil scientists have documented the long history of human-soil relations in Africa, Asia, Europe, and the Americas (McNeill & Winiwarter, 2004; Sandor, 2006). Amundson & Jenny (1991) evaluated the variety of ways that soils have been altered by Pacific island colonizers, indigenous peoples of North America, Midwestern USA farmers, and 19th and 20th century city-park managers. These effects were subsequently followed by the 20th century transformation of soils by human activities physically, chemically, and biologically. Geologic erosion rates have been accelerated several-fold even on a global scale, and valley morphologies are being restructured by deep deposits of legacy sediment (Merritts et al., 2011; James, 2013; Wade et al., 2019). Earth's surface and soils are constantly evolving and while the human influence on soils may be recognized to be extensive at 2000 BP and to have very clearly increased during the 20th century (Richter 2007), soil change is evolutionary and, fundamentally, human transformations of soil are diachronous.

A chronostratigraphic Anthropocene commencing in the mid-20th century definitionally excludes millennia of such earlier human influences (Ellis et al., 2016) but this does not decouple it from its historical and causative links (as, for instance, much of 20th century history is rooted in 19th century and earlier events). The situation is directly comparable to many of the chronostratigraphic boundaries of older parts of the GTS, where a correlatable horizon occurs within a continuum of long-term change, as at the base of the Cambrian System (Williams et al., 2014; Fig. 1 herein), and the base of the Silurian System (Zalasiewicz & Williams, 2014). This is true also of the base of the Meghalayan Stage of the Holocene Series where a chronostratigraphic boundary set at 4250 years (b2k) cuts seemingly arbitrarily across dramatic societal shifts brought about by a climate event that lasted ~250 years (Walker et al., 2019).

Global assessments of the timing of onset of landscape change from archaeological evidence commonly emphasize the long-term continuum. For instance, Stephens et al. (2019) showed how foraging, pastoralism, agriculture and urbanism developed between 10,000 years ago and 1850 CE, suggesting extensive transformation of the terrestrial landscape by 3000 years ago. Common with such analysis, though, the study does not investigate transitions during the Industrial Age and Great Acceleration (e.g. see also Fig. 1 of Ellis et al., 2013, which excludes the latest 100 years). Consequently, these more recent changes, larger to the extent of being 'off scale' when compared with the earlier ones of the Holocene, fall outside of the frame of reference selected (Syvitski et al., 2020).

These non-geological frameworks are valuable within their own contexts. González-Ruibal (2018) considered that the task of archaeology is not to define '–cenes' but to produce its own periodizations that range across time and space. Just as archaeologists distinguish the Palaeolithic and the Pleistocene, even if they occur approximately simultaneously (ca. 2.5 million to 11,000 years ago), alternative terms to the chronostratigraphic (geological) Anthropocene might be adopted to refer to different (if intertwined) phenomena. Such emergent terms could comfortably sit alongside, and fruitfully interconnect with, the Anthropocene as proposed by Crutzen and now being explored by the AWG.

5.2 Greenhouse gas emissions-based early Anthropocene

Ruddiman (2013, 2018) and Ruddiman et al. (2015, 2016), proponents of an informal 'anthropocene' or more recently of an "early anthropogenic hypothesis" (Ruddiman et al., 2020), also focused on early human impact, but emphasized the inferred atmospheric and climate effects of early farming. They suggested that the termination of the slow decline and beginning of a slow rise in atmospheric CO_2 and CH_4 levels, ~7000 and ~5000 years ago respectively (Fig. 2), were critical in preventing the onset of the next glacial phase, and hence are key to defining the Anthropocene. This scenario is attractive, and the CO_2 levels reached may well have been sufficient to delay the return of glaciation (Ganopolski et al., 2016). But the evidence overall suggests a more complex and ambiguous narrative. For instance, $\delta^{13}C$ studies and considerations of the oceanic carbonate patterns show that much of the extra atmospheric CO_2 was of oceanic origin (Broecker et al., 1999; Broecker & Stoker, 2006; see also Ahn & Brook, 2007), as natural ocean chemistry responded to the effects of declining insolation, or to changes in deep-ocean ventilation through the Holocene (Studer et al., 2018) rather than anthropogenic deforestation (see also Zalasiewicz et al., 2019b).

Whatever the source of the rise in CO_2 beginning 7000 years ago (arguably by large-scale use of fire to clear land by hunter-gatherers) and of CH_4 rising from 5000 years ago (more confidently explained by emissions from rice and livestock: Mitchell et al., 2013), these rises were small and gradual . They contrast substantially with what the world has experienced beginning ~1850 CE and much more sharply since 1950 CE – for which the analogy might be akin to the difference between walking down a gradually sloping ramp and falling off a cliff (Fig. 2).

Focusing on the detail of these slow, ramp-like changes, additionally, may obscure the much larger post-1850 CE – and especially post-1950 CE – rises in atmospheric CO_2 and CH_4 levels: by showing the information in schematic, non-scalar figures (e.g. Ruddiman et al., 2015; Ruddiman, 2018, fig. 1; Ellis et al., 2016) or simply by not using the data regarding modern times (~post-1850 CE) in illustration (e.g. Ruddiman et al., 2016).

Overall, therefore, the traces of events linked with the 'early Anthropocene' concept are either markedly diachronous (the spread of farming and urban settlements) or gradual (the pre-industrial rise in CO_2 and CH_4 levels). In some cases they hinge upon the local development of the archaeosphere – that is, the presence of anthropogenically worked ground overlying the 'natural' substrate. Because the lower bounding surface of the archaeosphere is so time-transgressive – varying in date from thousands of years old in places to 21st century in others – it does not support any specific date for the start of the Anthropocene, and this has been used to support conceptions of the Anthropocene as an informal globally diachronous event (Edgeworth et al., 2015, 2019; Bauer & Ellis, 2018). Regardless of whether the Ruddiman hypothesis is correct, the relatively small scale of change and paucity of isochronous stratigraphic markers 7000 years ago, compared with the mid-20th century, would not justify an epoch-level chronostratigraphic Anthropocene with an onset at this time.

Thus, none of these 'early Anthropocene' concepts are compatible with the requirements of a formal geological unit in the GTS. Instead, they reframe all or part of the Holocene and potentially parts of the Pleistocene too, to recognize the long record of humans in transforming the global environment. The historical justification for, and narrative of, the Holocene already includes the development of human civilizations and the related impacts (Walker et al., 2009; Gibbard & Walker, 2014). The impacts associated with industrialization continue this long record of perturbation – but with sharp increase in scale and speed, novel phenomena, and increasingly irreversible changes to the Earth System (Syvitski et al., 2020).

5.3 Other 'early Anthropocene' concepts

Of the various 'early Anthropocene' concepts, only one overtly sought to combine a multi-millennial Anthropocene span in concordance with standard procedures in defining a geological time unit (i.e., via a GSSP or 'golden spike') (Wagreich & Draganits 2018). These authors used evidence of early mining and smelting lead anomalies in various 'natural' archives to propose a lower boundary for the Anthropocene at one of two significant events: 1) at around 3000 BP with the first mining-induced spike of pollution, defined by lead enrichment and changes in $^{206}Pb/^{207}Pb$ ratios; or 2) at around 2000 BP associated with more extensive Roman mining. The signals are widespread, but nonetheless regional. Peat bogs throughout Europe offer clear evidence of Roman atmospheric Pb contamination (e.g. LeRoux et al., 2004; Monna et al., 2004; Cloy et al., 2005; Kylander et al., 2005; Shotyk et al., 2005), but there is no evidence of this signal in peat bogs sampled in North America (Shotyk et al., 2016; Pratte et al., 2017a, 2017b) or southernmost South America (Sapkota, 2006). The Wagreich & Draganits (2018) proposal of a GSSP based upon these far-field, albeit regional, stratigraphic records might be accommodated within the recent tripartite formal subdivision of the Holocene (Walker et al., 2018, 2019). However, the related shifts in Pb isotopic ratio are much smaller than early/mid to late 20th century isotope shifts observed across Europe due to widespread use of isotopically-distinct lead from Australian Precambrian Pb ores in leaded gasoline (e.g. Shotyk et al., 1998; Eades et al., 2002; Cundy & Croudace, 2017). The early Pb enrichments are also substantially smaller than those in the 19th and 20th centuries caused by increased coal burning and leaded gasoline use.

An alternative concept, intermediate between the 'early Anthropocene' and the one linked with modern industrialization, is that of an Anthropocene associated with the arrival of Europeans in the 'New World' in 1492. This event resulted in a major human population loss and replacement, increased globalization of human foodstuffs, regional forest recoveries and influx of neobiota (Lewis & Maslin, 2015; Koch et al., 2019). This option has raised considerable interest amongst social scientists given the linkage to European colonization, subjugation and extermination of indigenous peoples, and its contribution to expansion of the slave trade. These authors attribute the small but abrupt decrease in atmospheric CO_2 (the Orbis spike) at ~1610 CE, evident in the Antarctic ice core record, to depopulation and forest recovery across the Americas following the initial colonization. They proposed it as a potential GSSP associated with one synchronous event related to what was in fact a gradual, multi-decadal event triggered by human political and economic desires. Certainly, European expansion and the resulting damage to other human societies and ecosystems shaped the course of many diachronous disruptions to both natural and socio-economic realms for centuries to come, many of which can be felt in present societies. The Orbis spike is, however, not correlatable in most geological archives, reducing its potential to define a chronostratigraphical Anthropocene unit, and has questionable linkage to an anthropogenic cause (see Zalasiewicz et al., 2015), as ice core records of carbonyl sulfide show that a decrease in primary production and ecosystem respiration, and not vegetation regrowth, was the primary cause for the spike (Rubino et al., 2016). In any event, the magnitude of the Orbis spike (or dip) is dwarfed by the later increase in atmospheric CO_2, in particular since ca. 1950 CE (Fig. 2).

5.4 Wider relevance

The meaning of the Anthropocene to scholars of the social sciences, humanities and arts varies widely according to the disciplines and communities involved, and even among individual scholars within disciplines. Here, we can only sketch out a few fields where the Anthropocene concept has a particularly strong, and expanding, impact, including overviews of reactions of historians, political scientists, legal scholars, economists, and philosophers, to the concept. The patterns revealed might, perhaps, have more general application across other disciplines, though some other assessments (e.g. Conversi, 2020) emphasize the diversity of interpretation.

While most historians remain unconcerned by the concept of the Anthropocene, some subgroups – such as environmental historians, intellectual historians, economic historians, historians of science – have addressed it vigorously if not consistently. They remain divided about when it began (McNeill & Engelke, 2016; Austin, 2017). The leading positions are familiar ones within the Anthropocene debates: about 1950, about 1800, about 1500, or in deep human time.

Those historians who do embrace the concept, like many others in the humanities and social sciences, typically use the term more loosely than stratigraphers or Earth System scientists, with some exceptions (e.g., Thomas et al., 2020). They generally understand the Anthropocene as an interval of time during which humankind has exercised some unspecified degree of influence upon ecosystems, rather than the more restricted sense expressed in the mandate of the AWG: the interval in which "*human modification of natural systems has become predominant*" (SQS, 2009).

Historians are usually uncomfortable with efforts at globally synchronous dating and have never settled on a system of periodization for global history. They routinely use periodizations that vary from place to place, so Chinese history and African history have completely different schemes. Given this disciplinary tradition, it is easier for them to conceive of an Anthropocene that began earlier in one place and later in another – at odds with the rules of chronostratigraphy – than it is to conceive of "the species" as a historical agent of global transformation (Chakrabarty, 2009). The commitment to this traditional approach tempts historians to reject the chronostratigraphic Anthropocene because it requires global synchronicity. This preference for particularism over generalities appears equally in historians' resistance to grouping humankind together rather than foregrounding analysis of social groups. Historians often assert that such grouping hides the realities of inequality and exploitation, and that these subjects deserve prominence over others. The humanities typically ask for the human causes of the Anthropocene to be considered instead of the effects on geological strata or the Earth System. This outlook generates unease with both the concept and the term Anthropocene. Even so, chronostratigraphic units provide a unifying framework for all disciplines, and in history the purely temporal “15th and 16th centuries” is just as important for communication as is the “Renaissance” as a cultural period.

Taking another approach, some historians resist the impulse to define the Anthropocene for themselves, and ask not "when did the Anthropocene begin?" but "when did the human activities and ideas capable of producing the mid-20th century Anthropocene begin?" To this latter question, there are many answers both temporally and spatially. A subfield called Big History begins its historical narrative with the Big Bang (Christian, 2019), thus nesting human history within both cosmic and Earth history, while other research traces the deep history of institutions and technologies to suggest that patterns set in the deep past may have made the Anthropocene inevitable (Morris, 2014). Alternatively, historians point to the early modern period – by which they mean ~1450–1800 – when the energies and environmental luck of Western imperialists led to globalization and the shift in values that ultimately produced the Anthropocene (Pomeranz, 2000; Parthasarathi, 2011). Yet other historians argue that the forces cementing the rupture in the Earth System coalesced later. They explore the power unleashed by 20th-century inventions such as the Haber-Bosch process, antibiotics, and nuclear power, and developments such as postcolonial development and expanding production (Harper, 2017, 2020; Hecht, 2018; Brown, 2019). For these historians, the key is to differentiate the empirical task of defining the Anthropocene chronostratigraphically from the work of evaluating the human forces leading to it (Thomas, 2014).

As with historians, a small but growing subset of political scientists are adopting the Anthropocene as a framework for political analysis. Increasingly, instead of deconstructing the concept as a socially constructed meme (Di Chiro, 2016), they engage with the Anthropocene science. Understanding our new reality and providing improved forecasts of climate and environmental change does not, however, give easy political answers. Indeed, political scientists resist the implication that a planetary problem necessarily requires planetary governance (Arias-Maldonado, 2020; Dryzek & Pickering, 2019) and generally consider top-down, eco-authoritarian governance as neither feasible nor effective (Beeson, 2010). A central problem is that our inherited political institutions deal with the immediate and the near-term, oblivious to the larger scales required to comprehend the Anthropocene. They also tend to be committed to the economic growth that is driving the global changes of the Anthropocene. But an increasing number of political scientists now understand that the Earth System's habitability is at stake, and are considering new institutions, systems, and ideas that might lead to governance that accord with non-negotiable planetary thresholds (Dryzek & Pickering, 2019).

Until recently, the Anthropocene has likewise remained beyond the scope of international law, and thus peripheral to international legal scholarship. International law has been focused since its inception on political changes between states, not on changes in the Earth System conditions. The latter has been taken as a given, being assumed to be stable, based on centuries- (indeed, millennia-) long experience of Late Holocene conditions. This assumed stability has therefore been implicitly incorporated in the foundations of the present, territorially-based system of international law. A systemic challenge for international law is set to emerge when Earth System change, such as sea-level rise, will put into question the factual basis of current territorial divisions, impact on cross-boundary movements of human populations, and ultimately challenge the criteria for statehood as set by international law. As this process has begun, and is intensifying, the Anthropocene is therefore taking on political – and international law – relevance.

For international law scholarship, two links to the Anthropocene have emerged. Firstly, how core parts of international law, such as of the law of the sea but also of territory and its acquisition over centuries, facilitated the emergence of forces that led to ever-greater human impacts on the Earth System (Vidas, 2011; Viñuales, 2018). Secondly, how international law can evolve to be able to embrace the consequences of changes in the Earth System, and remain relevant for the regulation of inter-state relations (see, e.g., ILA, 2018). International law discussion concerning the Anthropocene is, however, less about its conceptual content and more about the consequences of the geological, Earth System change that it represents. This means that international law will largely rely on the geological interpretation of the Anthropocene, should it be formalized. Indeed, upon being formally adopted through a rigorous procedure within the competent geological/stratigraphic bodies, the scientific fact of the Anthropocene as a new epoch will become considered a fact of common knowledge – a 'notorious fact', with a legal implication of not being open to interpretation, but rather providing an inherent part of the overall context within which international law operates.

Mainstream economics generally ignores the Anthropocene because it treats the economy as separate from nature, with value calculated only, or primarily, on the basis of market exchanges. Public goods, such as clean air, which are not bought and sold, are invisible to the market and therefore have no value, a position first articulated by political economist Jean-Baptiste Say (1767–1832). Furthermore, modern economics essentially relies on assumptions of endless growth which puts the economy and our finite planet on a collision course (Higgs, 2014). The Anthropocene concept is therefore emerging among discussion of alternative economic models, particularly those which treat the economy as a subset of the natural world, in ecological economics (Brown & Timmerman, 2015), rather than vice versa, and that argue for limitations on growth – and even degrowth – to balance the non-negotiable limits on our resources and the needs of growing human populations (Raworth, 2017; Berners-Lee, 2019).

One of the most visible impacts of the Anthropocene concept has been in philosophy and social thought, though rather outside or on the fringes of the respective academic disciplines. Here, the Anthropocene is not seen as a problem of chronostratigraphy but as a fundamental 'predicament' (Thomas et al., 2020) that calls for a re-thinking of the conceptual basis of knowledge, ethics, politics, aesthetics, and society (Morton, 2013; Raffnsøe, 2016; Latour, 2017; Hamilton, 2017; Ghosh, 2017; Clark & Szerszynski, 2021). Some of these positions, such as those of Hamilton and Latour, explicitly emphasize the importance of engaging with geology, stratigraphy, and specifically with ESS and its novel understanding of nature as a single, integrated system. At the center of this approach is the question how the Anthropocene challenges human self-understanding, including social relations, human agency, and responsibility, as well as humanity's relation to nature. Other positions often grouped under the label 'posthumanism', question the idea of human exceptionalism. They emphasize the entanglement and symbioses of human beings with non-human entities and argue for an ethics of care and 'kin-making' with other species (Haraway, 2016, p. 103). Criticising an occidental tradition of 'anthropocentrism', they define human nature as "*an interspecies relationship*" (Tsing 2012, p.141) and call for an acknowledgement of both human dependency on and responsibility towards the non-human (cf. Horn & Bergthaller, 2020, p. 67-83)

Acknowledging the impact of human interference in Earth System functioning leads to questions about traditional ethical norms and potentially a redefinition of humanistic values such as liberty (Schmidt et al., 2016). This redefinition is not about abolishing these norms and values, but about reframing them within "*a different kind of orientation to the Earth, on in which we understand deeply our extraordinary power and unique responsibility"* (Hamilton, 2017, p. 151). Our new position vis-a-vis the Earth System also leads us to reconsider the forms of knowledge that made this interference possible and blinded us to its consequences. In order to recognize the predicament of the Anthropocene, some authors argue that we need new "knowledge regimes" beyond disciplinary boundaries (Renn, 2020) or a "multidisciplinary" exchange among the fields of research, diverse methods, and epistemological interests (Thomas et al., 2020).

While it is impossible to reconcile the many different approaches to the Anthropocene concept in history, economics, philosophy, law, ethics, and social thought, the contribution of the humanities and the social sciences can be understood as assuming a position of meta-reflection. While leaving questions of dating, definition and description of the Anthropocene to the sciences, this meta-reflection revolves around questions of responsibility, but also around re-defining what is human – such as forms of knowledge, society, culture, art – in the face of the Anthropocene.

6. Discussion

Differing interpretations of the Anthropocene have emerged since Paul Crutzen first launched the term into scientific discourse in 2000. The chronostratigraphic (geological) concept closely follows that of Crutzen, as a marked intensification of human impact, associated with global industrialization, becoming the predominant factor in pushing fundamental parts of the Earth System out of the conditions that prevailed over the great extent of the Holocene. This is most clearly seen in the pattern of the abrupt rise in atmospheric CO_2 and CH_4 to levels and rates of increase not seen, not only in the Holocene and late Pleistocene (Fig. 2), but throughout the preceding 2.6 million years of the Quaternary System/Period (Yan et al., 2019). But it is similarly well expressed in the perturbation of the N and P cycles and other global trends summarized in the 'Great Acceleration' graphs (Steffen et al., 2007, 2015; see also Syvitski et al., 2020); it is this mid-20th century level, mirrored by an array of proxy signals in recent strata, that is being followed by the AWG as the start of the proposed stratigraphic Anthropocene. Crutzen's concept was clearly framed as a geological time unit (using the term 'epoch' and clearly in relation to the Holocene), albeit being framed in ESS and not chronostratigraphic/geological terms. Examined in detail in formal stratigraphical terms, the amended version of Crutzen's concept has in effect been shown to provide the functional basis for a potential *formal* chronostratigraphic unit of both time and strata (i.e., an Anthropocene Epoch and Series), distinct from the Holocene Epoch/Series (e.g., Waters et al., 2016, 2018). This concept hence represents real and sharp change to the Earth System, and is valid from a chronostratigraphic perspective.

The archaeological/anthropological concept is valid also, although not oriented on the notion of *predominant* human impact. It is not compatible with this potential formal division of geological time, but may be complementary to it, in the same way that diachronous rock units and the processes that formed them are integrated with the synchronous boundaries of a chronostratigraphic time framework in geology. It is clear that humans since the Late Pleistocene and particularly through the Holocene have produced distinct, detectable, and unprecedented transformations of Earth's environments. These vary through time and space, but this diachroneity is not a barrier to naming time units (e.g., Palaeolithic, Bronze Age) in these disciplines. Use of the term Anthropocene more overtly signals this growing human imprint than does the more neutral term Holocene, even though one of the characteristics of the Holocene is its 'distinctive paleoenvironmental and unique anthropological record' (Walker et al., 2009, p. 4). (N.b. This opinion is not universal among archaeologists: Wuscher et al. (2020), with specific reference to the Anthropocene, note that contemporary urban reworking of the ground has little in common with historic and prehistoric archaeological signatures.)

The key functional difference between the archaeological/anthropological Anthropocene and the ESS/geological (chronostratigraphic) interpretation does not depend simply on stratal characterization. The sharpest (and putative 'primary') stratal marker for precise definition of the chronostratigraphic Anthropocene in geology appears to be the mid-20th century 'bomb spike' of globally disseminated radionuclides (Waters et al., 2015), and yet this in itself does not constitute an epoch-making change, particularly for a unit this brief. Rather, it is a widely recognizable marker that closely coincides with (e.g., Bancone et al., 2020, Fig. 1) the sharp and pronounced difference in trajectory of many key Earth System parameters that provided the initial impetus for the chronostratigraphic (geological) Anthropocene (quantified by Syvitski et al., 2020), and that remains the justification accepted by the AWG.

This is seen prominently in the steep rise in atmospheric CO_2 concentrations (Fig. 2), which clearly depart from the Holocene trend of overall stability. This rise has more or less direct effects: altering the heat balance of the Earth, storing heat in the oceans, heating the atmosphere, melting polar ice, inducing climateforced changes in the geographical ranges of biota, and lowering oceanic pH (with yet further biological effects). Some associated changes have no deep-time analogue: the hydrocarbons-powered reshaping of landscape associated with rapid urbanization and modern agriculture, and such industrial processes as large-scale nitrogen fixation and the synthesis of an unprecedented array of new mineral-like materials (Hazen et al., 2016), components of myriad rapidly evolving groups of technofossils, from skyscrapers to plastics, and their waste products.

As regards human and biological consequences, the Earth System based on many parameters remained fundamentally the same throughout the pre-industrial Holocene (or the bulk of the archaeological/anthropological Anthropocene), within the range of small Holocene variations prior to the Industrial Revolution (Fig. 2). It was broadly similarly habitable, from generation to generation for millennia, albeit with large variations such as the Green Sahara interval, megadroughts and other regional climate changes. The introduction of anthropogenic fire regimes, hunting of large land mammals, and plant and animal domestication fundamentally changed evolutionary processes and ecological functioning across the terrestrial biosphere and left diachronous signals in geological archives, but at rates that, whilst destabilizing local to regional ecologies, did not destabilize the Earth System as a whole.

The changes associated with the chronostratigraphic (geological) Anthropocene, by contrast, are now clearly destabilizing the Earth System globally, and this will continue from generation to generation over at least many millennia (even if anthropogenic forcing ceased tomorrow), as climate and sea level adjust to the new radiative balance and other perturbations run their course. It is these changes that human populations and ecosystems will need to mitigate or somehow adapt to. It is this Anthropocene which is referred to as a framing concept in, and gives urgency to, global assessments of such areas as human health (Whitmee et al., 2015; Willett et al., 2019), climate (IPCC, 2018, 2019), wildlife conservation (WWF, 2018), the environment and sustainability (EEA, 2020) and international law (Vidas, 2011; Vidas et al., 2015b, 2020; ILA, 2019). For, if the trends that characterized most of the Holocene duration (of human population growth, greenhouse gas emissions, mining, biotic changes and so on) had continued through into the present, there would be little need for a new geological time term, or for such global environmental assessments or the concerns that sparked them.

This raises two central questions: is there indeed a need for the Anthropocene as a new formal chronostratigraphic term in geology; and can the rank of epoch be justified when this would by default terminate the Holocene? Perhaps the need is effectively illustrated by the large and growing number of times “Anthropocene” has been cited in the scientific literature (Head, 2019). Formal definition clarifies and increases the utility of terms that are widely used but potentially ambiguous, and this would certainly apply to the chronostratigraphic Anthropocene. This was indeed the rationale for formalizing the terms Lower, Middle, and Upper as subseries of the Holocene (Walker et al., 2018, 2019). The rank of epoch can be justified on grounds that the Earth System left the Holocene envelope of pre-industrial variability in the mid-20th century, and it did so spectacularly owing to force-multiplying feedbacks in response to overwhelming human impacts. The planetary transformations associated with the Great Acceleration vastly outweigh in impact and in stratigraphic expression the 8.2 ka and 4.2 ka climatic events used to subdivide the Holocene. Given both the rate and scale of change marking the onset of the chronostratigraphic Anthropocene it would be difficult to justify a rank lower than series/epoch.

What the Anthropocene means to human experience more widely may be approached via philosophy, history, politics, law, economics and other fields dedicated to addressing issues of meaning and value. These disciplines are increasingly asking how and why these mid-20th century developments arose and what the rapid transformation of our planet means for human societies and their ideas of justice, decency, and order. The political, social, cultural, and economic antecedents of the Anthropocene are intrinsic to the fuller analysis of the concept, as are considerations of humanity's future. While some social scientists and humanists align their understanding of the Anthropocene with the chronostratigraphic and ESS definition of this phenomenon (e.g., Angus, 2016), others choose to redefine it or invent alternative terms such as Thanatocene, Thermocene and Capitalocene (see Hallé & Milon, 2020) to offer different models of explanation for the current ecological crisis, though some may include elements of distrust of science (in turn partially manufactured by political and corporate interests to give impetus to those who wish to reject scientific findings: Oreskes, 2019). It is not clear whether the formalization of the chronostratigraphic Anthropocene, should it occur, will have any impact on humanists, social scientists and others who are not ready to engage with the scientific approaches such as in chronostratigraphy and ESS. It is therefore important to consider how these various meanings might be managed in practical terms.

7. Potential acceptance and utility of the chronostratigraphic (geological) Anthropocene beyond geology

A situation has arisen where, as a result of different disciplinary perspectives, a widely useful term, which refers to a time when human forces shape nature, has evolved into overlapping but distinct concepts. This is not unique to the Anthropocene – many words have homonyms of identical spelling and sound but quite different meaning. Other words have a general meaning, and also a different or more specific meaning within an academic discipline. Within stratigraphic geology, for instance, such terms as ‘era’, ‘period’, ‘epoch’, and ‘age’ have highly specific meanings as different scales of time unit, quite distinct from their vernacular usage, and also their intended meaning within most humanities scholarship (where the Anthropocene may be referred to as an ‘era’ or as an ‘age’ without implying a specific stratigraphic meaning). ‘Soil’ also has different definitions in different disciplines – pedology, geomorphology, geology and civil engineering. This can lead to confusion, which may be avoided by taking care to specify the precise meaning intended in communication. Situations like this arise also in legal interpretation methodology under international law, where the "ordinary meaning" of a term – if not already strictly defined – is sought by means of interpretation (Vienna Convention, 1969).

The presence of a chronostratigraphic (geological) epoch/era distinction and its lack in vernacular use rarely causes major confusion in communication. However, the conceptual difference between a temporally recent, rigorously and precisely defined chronostratigraphic Anthropocene in geology and a more generally defined and earlier starting Anthropocene, the meaning of which can differ from study to study, seems great enough to potentially cause significant and widespread confusion and misunderstanding. Formalization of the geological meaning of the Anthropocene in stratigraphy – if this becomes the case – will likely contribute to the clarity of the term and facilitate its use, at least in geology and hopefully more widely.

Meanwhile, clarity of meaning might be gained by additionally qualifying the term. For instance, for the former, one may speak of the geological (and/or chronostratigraphic) Anthropocene, or use reference to a key publication, for instance the Anthropocene *sensu* Waters et al. (2016).

Others have also considered a "pre-" or "proto-Anthropocene", reflecting regionally dependent and non-synchronous impacts prior to the mid-20th century (Dubois et al., 2017). For example, the smelting of copper in Yunnan, China starting from c. 3400 BP (Dearing et al., 2008) clearly broke with earlier conditions and had a local environmental impact, but cannot be considered to define a global stratigraphic marker. The term 'Palaeoanthropocene' has also been proposed for the time of early anthropogenic impacts, prior to the Anthropocene *sensu stricto* associated with industrialization (Foley et al., 2013).

One might consider a capitalized 'Anthropocene' as representing the tightly defined geological, chronostratigraphic concept, with an uncapitalized 'anthropocene' being used for broader interpretations (cf. Ruddiman et al. 2015; Richter, 2020). This kind of distinction is used in geology, for instance to differentiate between the meaning of a sedimentary bed (informal) and a specific, defined lithostratigraphic 'bed' which has formal meaning and is capitalized, e.g. the Ludlow Bone Bed. Outside of geology, journalists and students of politics live with this problem with words such as Conservative/conservative; Democratic/democratic; etc., denoting a political party in some cases and a wider concept in others. Thus, one could refer to the "anthropocene" (uncapitalized), for instance *sensu* Ruddiman et al. (2015). Would such a subtle distinction (see discussion in Zalasiewicz et al., 2019b) help scientific communication? Perhaps, but this is made more difficult by the uppercased initial letter in Anthropocene being lost in the spoken word, and not being available in some non-English written languages, as in German or Spanish where all proper nouns have their initial letter capitalized, in Japanese where capitalization does not exist, and in Croatian where such proper nouns would not be capitalized.

Alternatively, given that there exist different concepts, then the most logical and compelling course of action may be to use different terms. The wide debate surrounding the concept has indeed led to the coining of over a hundred alternative terms which to varying degrees overlap with the Anthropocene (Hallé & Milon, 2020), each emphasizing particular aspects: these range from environmentally-based ones such as the Homogocene (Hassol & Katzenberger, 1995) or Homogenocene (Samways, 1999) – and so coined before Crutzen's term) – and Myxocene (Pauly, 2010) and the Pyrocene (Pyne, 2015) to sociopolitically-founded terms such as the Capitalocene (Moore, 2016) and Plantationocene (Haraway, 2015). Many of these terms were coined in order to criticize the Anthropocene concept by pointing to its philosophical or epistemological shortcomings and highlighting alternative causalities or effects of the current changes in the Earth system.

Even with some agreement on this point, though, means of regulation and enforcement are limited. Formal geological time terms (that may in time come to include the Anthropocene) may be closely regulated in Earth sciences publications, as authors need to follow technically-based editorial guidelines (in turn based on ICS guidelines), but this kind of 'clarity control' is in practice only effective within a specific discipline. Study of the Anthropocene(s) is now multidisciplinary, a development which has produced much that is positive, but which brings with it issues that require resolution. We encourage further discussion of this particular issue, of name and identity, among the scholarly communities involved, so that precise communication and effective collaboration in this important and wide-ranging area (Fig. 3) might be facilitated. We expect that the formalization of the Anthropocene through a rigorously regulated stratigraphic process, if resulting in a newly ratified geological time unit, can positively contribute to this cross-disciplinary debate, and help achieve clarity in the use of the term 'Anthropocene'.

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Tables

Table 1 *Examples of definitions and use of the term 'Anthropocene' in different disciplines*

Context	Meaning of the term 'Anthropocene'	Reference
Geology	"a distinct and globally near-synchronous body of strata characterised by a wide array of stratigraphic proxy markers, a unit that is most clearly recognisable as a globally near synchronous unit with a boundary placed somewhere around the 1950s"	Zalasiewicz et al. (2019a, p. 285)
	"a new geological epoch based on the recognition that contemporary human relations of production have irreversibly altered Earth's geological processes"	Tschirhart & Bloomfield (2020, p. 698)
	"the time interval in which earth's bio-geo-chemical processes are substantially influenced by human activities such that they leave a permanent record in the planet's rock strata"	Olvitt (2017, p. 396)
	"the geologic epoch in which we live, characterized by the global impact of human activities on Earth"	Rull (2017, p. 1056)
Earth System science (ESS)	"…the major and still growing impacts of human activities on earth and atmosphere, at all, including, global scales…"	Crutzen & Stoermer (2000, p. 17)
	"the current epoch in which humans and our societies have become a global geophysical force"	Steffen et al. (2007, p. 614)
	"…a sharp step change in the nature, magnitude, and rate of human pressures on the Earth System, driving impacts that push the system beyond the Holocene basin of attraction…"	Steffen et al. (2016, p. 336)
	"The formal establishment of an Anthropocene Epoch would mark a fundamental change in the relationship between humans and the Earth system"	Lewis & Maslin (2015, p. 171)
Geography	"the current state of planet Earth and the complicated relationship between *Homo sapiens* and Earth as our home"	Ziegler (2019, p. 272)
Social science (socio-economics)	"The 'Anthropocene' is defined by the observation that humanity has become a planetary force, on a par with the geological or climatic forces used to define phases of Earth history"	Fischer-Kowalski et al. (2014, p. 9)
	"This intervention questions the species category in the Anthropocene narrative and argues that it is analytically flawed, as well as inimical to action"	Malm & Hornberg (2014, p. 62)
	"The Anthropocene label, proposed in the 2000s by specialists in Earth system sciences, is an essential tool for understanding what is happening to us. This is not just an environmental crisis, but a geological revolution of human origin"	Bonneuil & Fressoz (2016, preface)
(environ-mental humanities)	"the discourse of the Anthropocene refuses to challenge human dominion, proposing instead technological and managerial approaches that would make human dominion sustainable"	Crist (2013, p. 129)

Archaeology and anthro-pology	"stratigraphic boundaries within archaeosphere deposits – marking the start of processes such as the spread of agriculture, diffusion of pottery or metal technologies, phases of industrialization, introduction of novel materials such as plastics and the advent of nuclear technology – would all be understood to indicate developments taking place within the Anthropocene"	Edgeworth et al. (2015, p. 53)
	"The initial domestication of plants and animals, and the development of agricultural economies and landscapes are identified as marking the beginning of the Anthropocene epoch"	Smith & Zeder (2013, p. 8)
Pedology	"a late Holocene start to the Anthropocene at approximately 2000 yr BP when the natural state of much of the terrestrial surface of the planet was altered appreciably by organized civilizations"	Certini & Scalenghe (2011, p. 1273)
	"the transition from pedology to anthropedology is forged not only by the mid–20th century's Great Acceleration of Steffen et al. (2015), but also by the many pedological studies that have explored the diachronous beginnings of human influences on soil"	Richter (2020, p. 8)
Ecology and conservation biology	"In ecology, the Anthropocene concept has focused attention on human-dominated habitats and novel ecosystems, while in conservation biology it has sparked a divisive debate on the continued relevance of the traditional biocentric aims"	Corlett (2015, p. 36)
	"A major consequence of coral reef ecological transitions is that the Anthropocene is likely to be defined by a progressive decoupling between current reef ecological states and the physical functions that reefs provide"	Perry & Alvarez-Filip (2018, p. 985)
	"Airborne and waterborne chemicals, lowered water pH, rising temperatures, increasing rates of extinctions, habitat fragmentation and loss, non-native invasive species, and new diseases have not yet altered key aspects of every ecosystem"	Caro et al. (2011, p. 185)
Philosophy	"an expression of modernity, an attack on Earth and the biosphere, or a biological imperative that is inherent to human existence"	Rull (2017, p. 1056)
	"To live in the epoch of the Anthropocene is to force oneself to redefine the political task par excellence: what people are you forming, with what cosmology, and on what territory?"	Latour (2017, p. 143)
	"Humans are more powerful; nature is more powerful. Taken together, there is more power at work in Earth."	Hamilton (2017, p. 45)
History	The Anthropocene "spells the collapse of the age-old humanist distinction between natural history and human history"	Chakrabarty (2009, p. 201)
	"the screeching acceleration of so many processes" that "the human race, without intending anything of the sort, has undertaken a gigantic uncontrolled experiment on the earth"	McNeill (2001, p. 4)
	"the Anthropocene encapsulates the evidence that human pressures became so profound around the middle of the 20th century that we blew a planetary gasket"	Thomas (2019, p. 1)
International Law	"the definition of current international law is, in many respects, that of a *system of rules resting on foundations that evolved under the circumstances of the late Holocene,*	Vidas et al. (2015, p. 4)

	assumed to be ever-lasting. […] The change introduced in that underlying element of stability – and that is what the transition from the Holocene to the Anthropocene involves – contains the potential for an unprecedented type of tension in relations between states"	

Figures

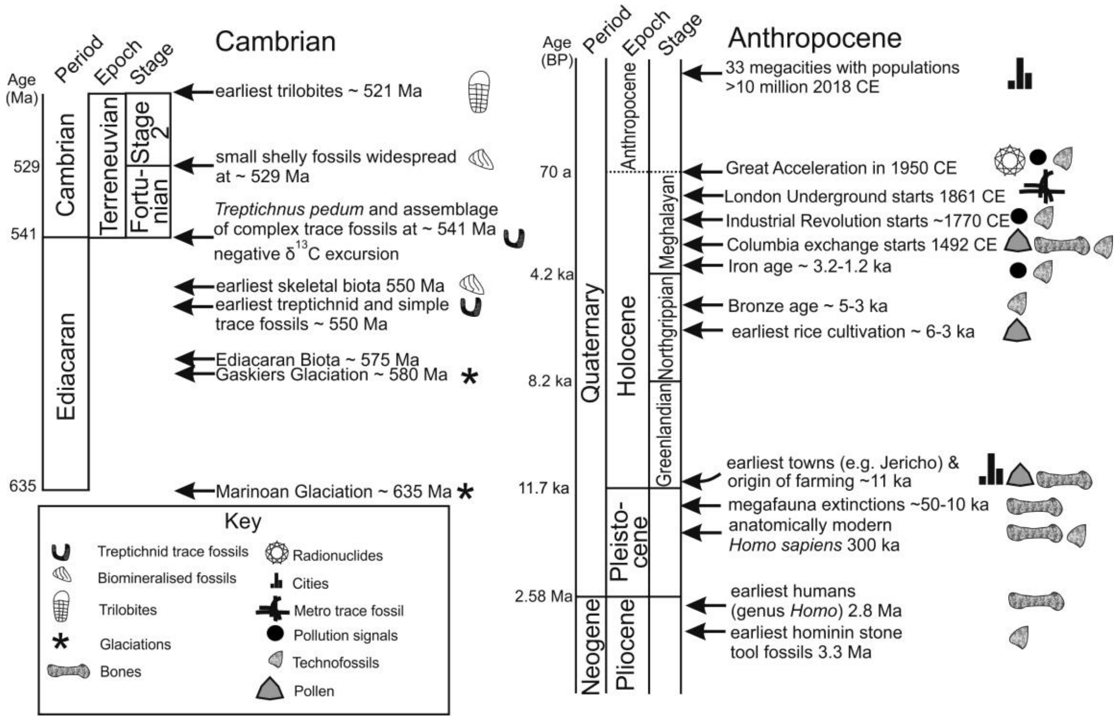

Figure 1 A comparison of events associated with the transition from the Ediacaran to the Cambrian periods, 541 million years ago, and the transition from the Holocene to Anthropocene in recent times. In each case, there is a succession of events that take the Earth System, over time, from one state to another, and in each case, to establish a geological time boundary, the most practicably correlatable (and therefore mostly nearly globally synchronous) signal needs to be chosen as primary marker in formally defining the respective time intervals. Adapted from Williams et al. (2014). Not to scale.

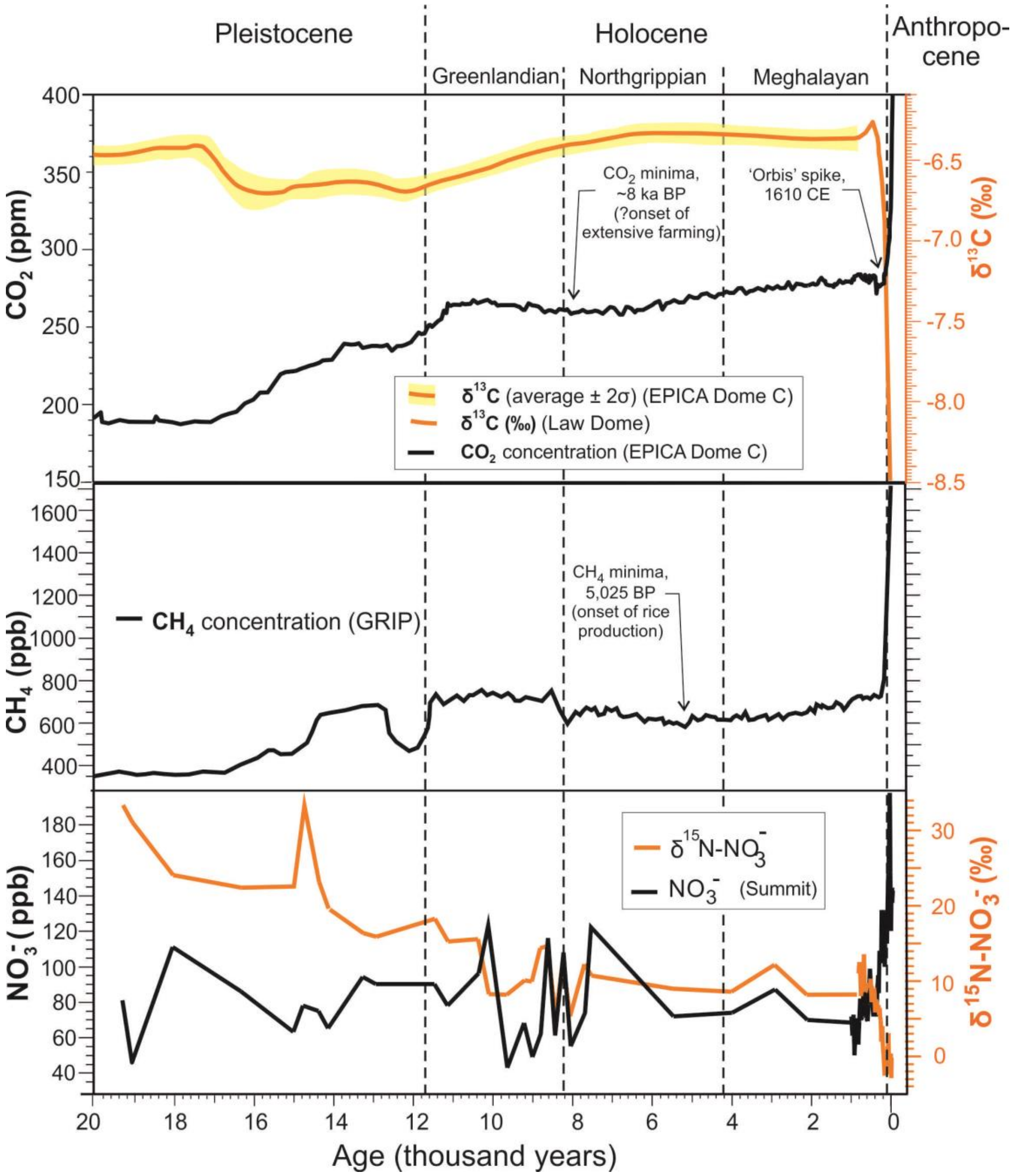

Figure 2 Comparison of key trends in the Holocene and Anthropocene, adapted from figure 2 in Zalasiewicz et al. (2019b). See Waters et al. (2016) for sources.

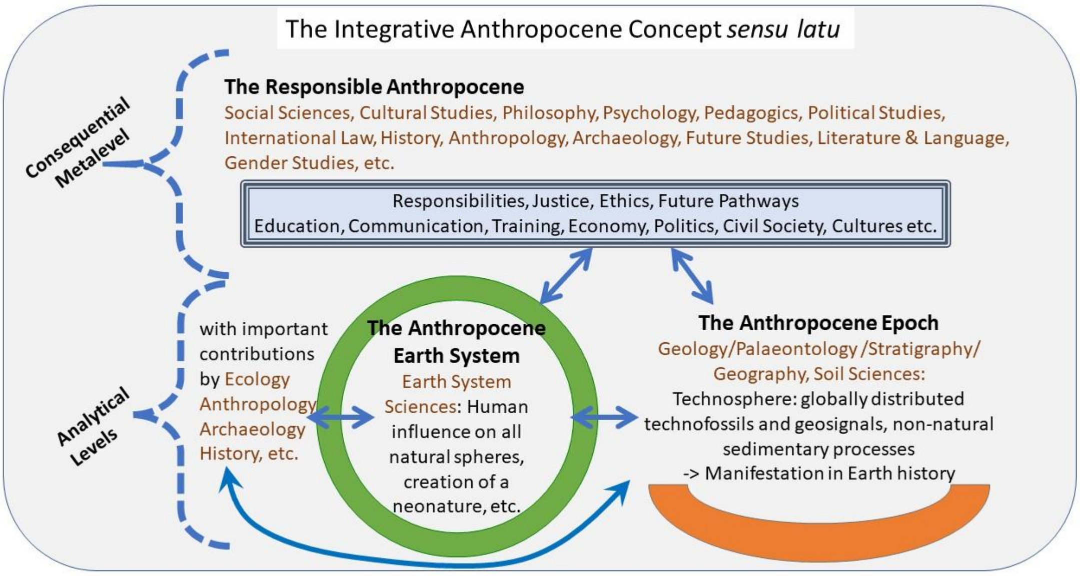

Figure 3 Opening further discussion: Sketch of a possible integrative and extended multilevel Anthropocene concept, highlighting systemic and interlocking interdisciplinary and transdisciplinary approaches (Based on Leinfelder, 2018, Fig. 2; see also discussion draft by Leinfelder, 2020). "Anthropocene" in the humanities and social sciences is a synthetic, less precise term that hints at an understanding of human responsibility. Instead of being an issue of precise definition, it begets criticism and debate (including the alternative terms) in order to better understand the deeper (i.e. political, ethical, cultural, epistemic etc.) implications of the diagnosis inherent in the scientific term. Formalization of the term is one side of the debate, and it will form an important point of reference for the humanities and social sciences to engage with the science. On the other hand, the humanities/social sciences aim at a more differentiated and thus more flexible understanding of the Anthropocene as a human-influenced state of the Earth system as a cultural threshold. This wider understanding should be seen as *complementary* to the very precise, narrow understanding in geology/ESS. While the scientific term is descriptive and analytical with regard to a given state of affairs, the humanities term is either normative (what should we do now?) or narrative ("how did we get here?"), or both ("why did we get there?").