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Anthropocene: Earth System, geological, philosophical and political paradigm shifts

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Abstract

The concept of the Anthropocene has created a profound paradigm shift within the scientific community that may well create equally important changes in philosophy and politics. There is general scientific agreement that human activity has been a geologically recent, yet profound, influence on the Earth System. The magnitude, variety and longevity of human-induced changes, to the lithosphere, hydrosphere, cryosphere, biosphere and atmosphere, suggests that we should refer to the present, not as within the Holocene Epoch (as it is currently formally referred to), but instead as within the Anthropocene Epoch. Hamilton (2015) argues that many commentators fail to acknowledge this paradigm shift and suggests the discussion of when the Anthropocene Epoch started is a distraction and irrelevant. Earth System scientists, such as ourselves, would argue that the evidence for the Anthropocene is already accepted and that the paradigm shift has already occurred. The current discussion has moved forward and is now centred on defining the start of the epoch using the fundamental principles of stratigraphy. We explain how geological time is divided up and the fundamental role of Global Stratotype Section and Points (GSSPs). We go beyond Hamilton's (2015) limited discussion and argue that the Anthropocene is creating paradigm shifts beyond the natural sciences. We also argue that there are multiple definitions of the Anthropocene and even if a formal definition of the Anthropocene Epoch is agreed by geoscientists, this would in no way invalidate other definitions or uses. It is the utility and wide appeal that makes the Anthropocene such an important concept.

Keywords

Anthropocene, Earth System, global environmental change, golden spikes, GSSP, paradigm shift

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Introduction

The Anthropocene as an idea is extremely powerful and therefore provokes powerful emotions. An example of this is Hamilton (2015) who argues that many scientists, including ourselves, have failed to recognise the Anthropocene as a fundamental shift in an underlying scientific paradigm. At the heart of his argument is that the 'global environment' is not the same as the 'Earth System', though many scientists use them interchangeably (Lewis and Maslin, 2015a). However, we hoped that we had been clear about this, given that the opening line of Lewis and Maslin (2015a) stated 'Time is divided by geologists according to marked shifts in Earth's state'. To move between the Earth in one state to another requires a change to the Earth System. Geologists have long considered the Earth as an integrated system as they have uncovered the major events in Earth's 4.6 billion year history, which form the basis of the Geologic Time Scale within which the Anthropocene may, or may not, be included in the future. Moreover Hamilton's (2015) definition of the 'Earth System' leaves much to be desired. The quote he uses from Langmuir and Broecker (2012) contains no mention of biology. But Earth scientists and Earth System scientists all agree that the biosphere has a huge influence on the Earth System; ranging from the speed of tectonic plate movements to chemical composition of the atmosphere, from the rate of mountain erosion to the intensity of the hydrological cycle. Indeed, life is what separates Earth and its functioning from other planets. Hamilton (2015) also asserts that human activity has changed the functioning of the Earth System. True, but it should also be noted that the fundamental processes governing the Earth System are the same now as in the past. The only difference is that human activity is a major force influencing the trajectory of the Earth System instead of all the usual non-human forces of nature.

Hamilton (2015) falls into two traps. The first one is the trap of *Anthropocentrism*, as he sees the Anthropocene as geologically different because it involves humans. He invokes the image that humans have taken the Earth's global functioning outside of natural variations. This is, however, simply a matter of timescale. For example, the natural Earth System without humans has been a lot warmer and colder than the present day (Maslin, 2013). Greenhouse gas concentration in the atmosphere has been a lot higher in the geological past than today, and there have been five mass extinctions that likely exceeded the present extinction rate. The second trap that Hamilton (2015) falls into is misunderstanding the difference between the evidence that we are in the Anthropocene and the formal definition of when this epoch may have started. The former, as we suggested at the beginning of Lewis and Maslin (2015a), and argue below, has been accepted and that is why most of the discussion is now related to defining the start of the new epoch, now that it is collectively acknowledged we are in the Anthropocene. In this paper we present our evidence that the Anthropocene is indeed a new geological epoch if we stick to the usual geological rules. We show that the paradigm shift has already occurred in science and we go beyond Hamilton (2015) and argue that it is a major conceptual jump in philosophy, history and geopolitics (e.g. Castree, 2014; Chakrabarty, 2009, 2015a, 2015b; Clark, 2012; Dalby, 2007; Harari, 2014; Johnson and Morehouse, 2013; Latour, 2015; Vidas, 2014; Yusoff, 2013). We also discuss that there should be multiple definitions of the Anthropocene and the formal geological definition of the Anthropocene Epoch should just be one of them.

Scientific paradigm shift

We disagree with Hamilton (2015) that there is a general ongoing Earth System science paradigm shift occurring. It has already happened. In 2001 the Amsterdam Declaration on Earth System Science stated, 'The Earth system behaves as a single, self-regulating system comprised of physical, chemical, biological and human components'. This was signed by four different research programmes – the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme on Global Environmental Change (IHDP), the World Climate Research Programme (WCRP) and the international biodiversity programme DIVERSITAS. Specifically on the Anthropocene, Lewis and Maslin (2015a) summarised the scientific evidence showing that the Earth System has been fundamentally altered by humans. But it is worth repeating this evidence again, as Hamilton (2015) argues that we and other commentators have distorted this view. If we start with the atmosphere there is clear evidence that human actions have released 555 petagrams of carbon (where 1 Pg = 10^{15} g = 1 billion metric tonnes) to the atmosphere since 1750, increasing atmospheric CO_2 to a level not seen for at least 800,000 years, and possibly several million years (IPCC, 2013), thereby delaying Earth's next glaciation event (Tzedakis et al., 2012). The released carbon dioxide has also increased ocean water acidity at a rate probably not exceeded in the last 300 million years (IPCC, 2013). Despite the focus on greenhouse gases because of concerns about climate change, humans have also profoundly affected other parts of the Earth System, for example the nitrogen cycle. The early-20th-century invention of the Haber–Bosch process, which allows the conversion of atmospheric nitrogen to ammonia for use as fertiliser, has altered the global nitrogen cycle so fundamentally that the nearest suggested geological comparison refers to events about 2.5 billion years ago (Canfield et al., 2010).

There is clear evidence that humanity is changing Earth's climate through anthropogenic greenhouse gas emissions (IPCC, 2013). These changes include a 0.85°C increase in average global temperatures and sea-level rise of over 20 cm over the last 100 years. There is also evidence for significant shifts in the seasonality and intensities of precipitation, changing weather patterns, and the significant retreat of Arctic sea ice and nearly all continental glaciers. It is estimated that Greenland is losing over 200 gigatonnes of ice per year, a six-fold increase since the early 1990s (IPCC, 2013), while Antarctica is losing about 150 gigatonnes of ice per year, a five-fold increase since the early 1990s and most of this loss is from the northern Antarctic Peninsula and the Amundsen Sea sector of West Antarctica (IPCC, 2013).

Human action also affects non-human life. Over recent decades, global net primary productivity appears to be relatively constant (Running, 2012); however, the appropriation of 25%–38% of net primary productivity for human use (Krausmann et al., 2013; Running, 2012) reduces the amount available for millions of other species on Earth. This land-use conversion to produce food, fuel, fibre and fodder, combined with targeted hunting and harvesting, has resulted in species extinctions some 100 to 1000 times higher than background rates (Barnosky et al., 2011), and probably constitutes the beginning of the sixth mass extinction in Earth's history (Barnosky et al., 2011). Species removals are non-random, with disproportionate removal of animals with larger body size from both the land and the oceans. Organisms have been transported around the world, including crops, domesticated animals and pathogens on land. Similarly, boats have transferred organisms among once-disconnected oceans. Such movement has led to a small number of extraordinarily common species, new hybrid species (Thomas, 2013), and a global homogenisation of Earth's biota. Ostensibly, this change is unique since Pangaea separated about 200 million years ago (Baiser et al., 2012), but Lewis and Maslin (2015a) argue that such trans-oceanic exchanges probably have no geological analogue.

Furthermore, human actions may well constitute Earth's most important evolutionary pressure (Darimont et al., 2009; Palumbi, 2001). The development of diverse products, including antibiotics, pesticides and novel genetically engineered organisms, alongside the movement of species to new habitats, intense harvesting and the selective pressure of higher air temperatures resulting from greenhouse gas emissions, are all likely to alter evolutionary outcomes (Darimont et al., 2009; Palumbi, 2001; Stuart et al., 2014; Tabashnik et al., 2014). Considered collectively, there is no geological analogue (Lewis and Maslin, 2015a; Palumbi, 2001). Furthermore, given that the average species occurrence is 1–10 million years, the rates of anthropogenic environmental change in the near future may exceed the rates of change encountered by many species in their evolutionary history. Human activity has clearly altered the lithosphere, hydrosphere, cryosphere, atmosphere and biosphere, and thus the Earth as an integrated system, including its future trajectory.

Kuhn (1962) defines a paradigm shift as a change in the basic assumptions within the ruling theory of science. We would contend that within the field of Earth System science the Earth's functioning as an integrated system is entirely uncontroversial, and the evidence for humans being a major geological power has been accepted and the paradigm shift has occurred (Lewis and Maslin, 2015a; Steffen et al., 2015; Zalasiewicz et al., 2011, 2015). That human activity has altered Earth fundamentally is rarely questioned within scientific publications. What is now being discussed is exactly how to formally define the Anthropocene Epoch so this paradigm shift can be ratified as part of the Geologic Time Scale, and more easily discussed and debated within and beyond the scientific community. In many ways the theory of plate tectonics example (Oreskes, 1999) presented by Hamilton (2015) is a false one, as we and many other Earth System scientists would argue that the basic science relating to the Anthropocene is already accepted after only a few years on from Crutzen and Stoermer's (2000) recent highlighting of the concept.

Philosophical paradigm shift

The paradigm shift in science to recognise that humanity is a power of geology is profound and influences fields beyond Earth System science. But we should be clear that this shift in the scientific paradigm, through complex social processes, is *a better*, not just different understanding of the world. This is because a common misinterpretation of paradigms is the belief that the discovery of paradigm shifts and the dynamic nature of science is a case for relativism, i.e. that science only has subjective value according to differences in perception, consideration or beliefs. Kuhn (1962, 1977) vehemently denied this as rational assessment of the weight of scientific evidence means the new paradigm, if evidence-based, is always superior to the previous theory. However, to be able to discuss and translate the new scientific concept of the Anthropocene it needs to be defined. All previous periods of geological time have been defined through the process outlined in the *Geologic Time Scale* (Gradstein et al., 2012; also see Smith et al., 2014) and hence the same scientific process is being followed for the Anthropocene. Thus, the comment that it is 'bold' that the International Commission on Stratigraphy set up a working group on the Anthropocene is incorrect. It is normal practice. Some commentators such as Ruddiman et al. (2015) wish to keep the term Anthropocene vague and undefined. This is partly because they are concerned that a formal definition of the Anthropocene would not include the early effects of human agriculture on both the landscape and atmospheric greenhouse gases. However, we see these and even earlier influences can be easily acknowledged as described as the 'palaeoanthropocene' (Foley et al., 2013). Others such as Hamilton (2015) and Zalasiewicz et al. (2015) are convinced that the Anthropocene must be formally defined as 1945 or 1950 to coincide with the early part of the Great Acceleration (Steffen et al., 2015). However, these studies neglect the fact that epochs typically last millions of years, and many of the changes they describe may be ephemeral changes to the Earth System. The need for clear long-term irreversible changes in the Earth System is also the reason why the discussion is only about defining the Anthropocene as an epoch and not a period on the same level as the Quaternary, as we do not currently know whether human impacts will stop the glacial–interglacial cycles which define the current Quaternary Period.

We argue that acknowledging and defining the Anthropocene would be a major shift in the way that we see the world, but the tools for deciding the definition will be the usual ones. The key difference geologically between the Anthropocene and other epochs is the cause of the change in the state of the Earth System. Thus Hamilton's claim that the Anthropecene 'can be like no previous one and the conventions will have to change' is incorrect. However, in terms of the way we see the world the shift is profound because adopting the Anthropocene Epoch reverses 500 years of scientific discoveries, which have continually moved humans to ever-increasing insignificance. The Copernicus 16th century revolution put the Sun at the centre of the solar system, downgrading the Earth. Modern cosmology suggests our Sun is one of 10^{24} stars in the Universe, each one with the potential to have planets. Darwin's 19th-century discoveries and the development of evolutionary science established that humans are merely a twig on the tree of life with no special origin. In the 21st century, adopting the Anthropocene reverses this insignificance: humans are not passive observers of Earth. *Homo sapiens* are central because the future of the only place where life is known to exist is being determined by the actions of humans. In fact, we would argue that humanity has become a geological superpower.

Defining geological time

There are currently two different Anthropocenes, and two different debates. One debate concerns informal use of the Anthropocene concept to recognise the influence of humans on the global environment or the Earth System. The second debate focuses on the formal definition of the Anthropocene Epoch by geoscientists. Hamilton (2015) mixes and twists these two debates, which is not helpful. It is the second debate, which Hamilton (2015) rather patronisingly refers to as the 'golden spike fetish', which was the focus of Lewis and Maslin (2015a). We certainly agree with Hamilton (2015) that the 'marker is not the epoch'; the marker is just the boundary that fits with geological conventions. The epoch is the Anthropocene, a change in the state of the Earth driven by humans. This failure to understand the importance and role of such markers appears to be due to a lack of understanding of the detailed work that goes into defining and refining the understanding of geological time.

In practice, the formal definition of any geological stage is a long and bureaucratic process that has been followed for every single geological boundary definition (Smith et al., 2014). It is worth summarising how geological time is understood so that similar confusion does not arise in future discussion. Geological time is divided into a hierarchical series of ever-finer units, the finest being stages, with stages nested within epochs, and so on (Smith et al., 2014). The present, according to the *Geologic Time Scale* (Gradstein et al., 2012), is in the Holocene Epoch (Greek for 'entirely recent'; started 11,650 BP, where present is defined as 1950), within the Quaternary period (started 2.588 million years ago), within the Cenozoic era ('recent life'; started 66 million years ago) of the Phanerozoic eon ('revealed life'; started 541 million years ago). Divisions represent differences in the functioning of Earth as a system and the concomitant changes in the resident life-forms. Larger differences result in classifications at higher unit-levels.

Formally, geological time units are defined by their lower boundary, that is, their beginning. Boundaries are demarcated using a GSSP (Global Stratotype Section & Point), or by an agreed date, termed a GSSA. For a GSSP, a 'stratotype section' refers to a portion of material that develops over time (rock, sediment, glacier ice), and 'point' refers to the location of the marker within the stratotype. These 'golden spikes' are a single physical manifestation of a change recorded in a stratigraphic section, often reflecting a global-change phenomenon. These are then complemented by other stratigraphic records showing a global change to the Earth System (Smith et al., 2014). Thus for a long-term change to the Earth from one state to another a single boundary time is chosen at a specific point within that long-term change. The definition of each GSSP differs and combines these requirements depending upon the time period, sediment types that are available and the types of change occurring at that point within Earth's history. Importantly, markers themselves are not required to encompass the complete change in the Earth from one state to another, nor, as Hamilton (2015) incorrectly suggests, are they chosen relative to some parameter exceeding some prior bounds of variability. Critically, it has been decided that within the Phanerozoic (last 541 million years) GSSPs define the boundaries, with a major scientific effort to define these under way. Currently 65 of the likely 102 Phanerozoic GSSPs have been ratified by the International Commission on Stratigraphy (ICS) while several others await ratification or selection from competing candidate locations (Smith et al., 2014). We should note that there is no requirement, as Hamilton (2015) suggests, that new species are required to define an epoch. There is a strong move over the past decade or more to define boundaries with chemical markers, as these are less diachronous than biostratigraphic markers (Smith et al., 2014). The Holocene Epoch was formally ratified in the absence of new species (Walker et al., 2009).

It is also possible, following a survey of the stratigraphic evidence, that a GSSA date may be agreed by committee to mark a time unit boundary. GSSAs are common in the Precambrian (>630 million years ago) because well-defined geological markers and clear events are less obvious further back in time. Regardless of the marker type, formally ratifying a new Anthropocene Epoch into the GTS would first require a positive recommendation from the Anthropocene Working Group (AWG) of the Subcommission of Quaternary Stratigraphy. This would be followed by a supermajority vote of the International Commission on Stratigraphy (ICS), and finally ratification by the International Union of Geological Sciences (see Finney, 2014, for full details).

In Lewis and Maslin (2015b) we respond to the specific concerns of Hamilton (2015) about our two suggestions for possible boundaries to define the inception of the Anthropocene Epoch: the irreversible exchange of species following the collision of the Old and New Worlds, coupled with the decline in CO_2 at 1610 CE (Orbis spike), which marks Earth's last synchronous cool period before the long-term warmth of the Anthropocene; and the accelerated changes to the Earth System in the second half of the 20th century, conveniently marked by the 1964 peak in radionuclide fallout (Bomb spike).

There has been no decision about the formal definition of the Anthropocene Epoch as yet. Moreover, even if there were a formal definition of the Anthropocene Epoch this definition should in no way prevent authors from understanding the Anthropocene in other ways, as long as they define how they are using the informal term. Indeed geological convention allows both to be easily discussed; formal names have capitalised designation, informal terms do not. Anthropocene Epoch is a formal geological term, while Anthropocene epoch or just the Anthropocene can be used as the informal term.

Anthropocene confusion

Confusion has arisen over the Anthropocene because of the assumption that defining the Anthropocene Epoch is *the* definition of the Anthropocene. In fact it is just the definition of a geological stage by geologists who have a long scientific tradition and institutions to investigate the major events in Earth's history and define geological time. Any formal definition of the Anthropocene Epoch does not invalidate other definitions. Geoscientists would never claim to have the ability nor legitimacy to define the beginning of historic periods, the emergence of important changes to economic or political systems. It may well be that the specific date associated with the geological definition of the Anthropocene, following the usual GSSP criteria, does not make a major contribution to the understanding of history or political science or philosophy. But the fact that we are today in the Anthropocene may well be important to these fields. We would therefore argue it is incumbent on other subjects such as history, political science, geography, etc., to have their own definitions of the Anthropocene, if these are useful within these domains. Moreover if the term Anthropocene is not fit for purpose within the disciplines then other terms, such as Capitalocene or Anglocene (Bonneuil and Fressoz, 2013), should of course be used if they are helpful to our understanding of the human influence on the Earth System. Nevertheless, for the AWG, the final report to the ICS must be based on the fundamental principles of stratigraphy and be able to be defended scientifically against accusations of political bias or agenda. If the AWG does not follow these principles it would be unlikely that the ICS will ratify the Anthropocene Epoch and the discussion and debate will continue. We would suggest that Hamilton (2015) and many other commentators must separate the argument for defining the Anthropocene Epoch from both the general agreement that humans are rapidly changing the Earth as an integrated system, and the more fluid and broader use of the Anthropocene concept.

Conclusion

The discussion of the Anthropocene concept both as an informal and a formal definition has changed the way we think about the relationship between humans and the Earth System. No longer are humans easily considered 'other' or 'outside nature' but rather now can be seen as one of the most powerful driving forces of change 'within' and 'part of' the Earth System. It is clear that scientists have already accepted the Anthropocene (Lewis and Maslin, 2015a; Rose, 2015; Steffen et al., 2015; Zalasiewicz et al., 2015), so Hamilton's (2015) claims that we, and others, are ignoring the paradigm shift is simply wrong. The slow careful bureaucratic approach of geoscientists to defining distinct periods of time is one of the great advantages in the discussion of the Anthropocene. Because it conforms to Stengers' (2010) call for 'slow science', it allows for the full discussion of the currently available evidence, it can identify, as do Lewis and Maslin (2015a, 2015b), gaps in our knowledge that need to be addressed and it can consider evidence from a wide range of disciplines. The definition of any formally ratified Anthropocene Epoch will be based on the fundamental principles of stratigraphy and the selection of a GSSP (Smith et al., 2014). Hamilton (2015), unfortunately rather ignorantly dismisses this process as 'golden spike fetish', despite the fact that geologists have spent decades painstakingly undertaking careful work to define and refine stage boundaries within the Geological Time Series (Gradstein et al., 2012). The result is an increasingly clear history of the major events in Earth's history, itself a major scientific achievement. We do feel this work should not be so lightly dismissed.

We also stress that the definition of the Anthropocene Epoch should not be seen as the only useful definition of the Anthropocene. The Anthropocene is emerging as an extremely useful concept in other disciplines such as history, geography, anthropology, political science and philosophy. Therefore there must be room for the formally stratigraphically defined Anthropocene Epoch and the more fluid and broader use of the Anthropocene concept. Of course, in many ways it does not matter which definition of the Anthropocene Epoch is used, so long as it is clearly stated, because it is the debate and discussion within and beyond science about human impact of the Earth System, which is the true paradigm shift in our thinking.

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