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The "Anthropocene": neglects, misconceptions, and possible futures

The term "Anthropocene" is often erroneously used, as it is not formally defined yet

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The term "Anthropocene" to describe anthropogenic global changes and their socio-political and philosophical repercussions has gained popularity during the past years. Although it originated as a scientific term to designate the geologic epoch in which we live, characterized by the global impact of human activities on Earth [1], "Anthropocene" has adopted a variety of meanings in many other areas such as philosophy, sociology, communication, politics, or law. In philosophy, the "Anthropocene" has become an expression of modernity, an attack on Earth and the biosphere, or a biological imperative that is inherent to human existence. In a political context, it has been contemplated a logical consequence of global capitalism or the decoupling between environmental health and human welfare [2].

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Notwithstanding its frequent and widespread use, however, the appropriateness of the term and concept of the "Anthropocene" is under vibrant debate. This essay aims to clarify the issue and briefly discuss some points that are often ignored or go unnoticed. First, the concept of the "Anthropocene" is not a recent invention but was first proposed about one century and a half ago albeit under a different name. Second, its frequent and extended usage may create the misconception that the term is already a formal official unit of geologic time scale, but it is not. Third, the current definition of "Anthropocene" is a bet on the future and, as such, its meaning and eventual formalization depend on the future development of human affairs.

The precursors of the "Anthropocene"

In geology, "-cene" is the suffix for an epoch, whereas "-zoic" is the corresponding suffix for an era. Geological time units are rock layers, called strata, organized into sequences. The geological branch that studies these strata and their chronological succession is stratigraphy. The Danish chemist Paul Crutzen and the American ecologist Eugene Stoermer coined the term "Anthropocene" a couple of decades ago [1]. But the idea of a new unit of the geological time scale (GTS) characterized by the human impact on Earth was already advanced in 1873 by the Italian geologist and priest Antonio Stoppani (Fig 1), who proposed the name "Anthropozoic" and that the new unit should have the rank of an era [3]. He accurately described how what he called "human relicts" (tools, weapons, buildings, and products of art and industry) and other evidences of human activities have been accumulating in the Earth's surface in recent slumps lacustrine and marine sediments, alluvial plains, deltas, marshes, peat bogs, caves, glacial moraines, or volcanic rocks. According to Stoppani, the "Anthropozoic" era should begin with the stone age with the first appearances of carved stone. However, Stoppani realized that these human relicts appeared at different times at different regions of the planet and it would be difficult to find an initial date of global value. Despite being a novel idea on sound geological grounds, the "Anthropozoic" was lost over time.

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Other terms appeared, as, for example, the "Psychozoic", or the "reign of mind", proposed by the American physician and geologist Joseph Le Conte in 1883. It would start in the Neolithic with the development of polished stone tools and the worldwide expansion of agriculture, but Le Conte did not emphasize the influence of human activities on Earth or the geological record as Stoppani did. In 1922, the Russian geologist Alexei Pavlov coined the term "Anthropogene" ("-gene" is the formal suffix for a geological period) based on the emergence of the genus *Homo*, which would be more or less equivalent to the present Quaternary period. In 1924, the French theologist Pierre Teilhard de Chardin, the French mathematician and philosopher Édourad Le Roy and the Ukrainian chemist Vladimir Vernadsky, the father of biogeochemistry, proposed the term "noosphere" or the "sphere of mind" in analogy to the atmosphere or the biosphere. The noosphere was initially a

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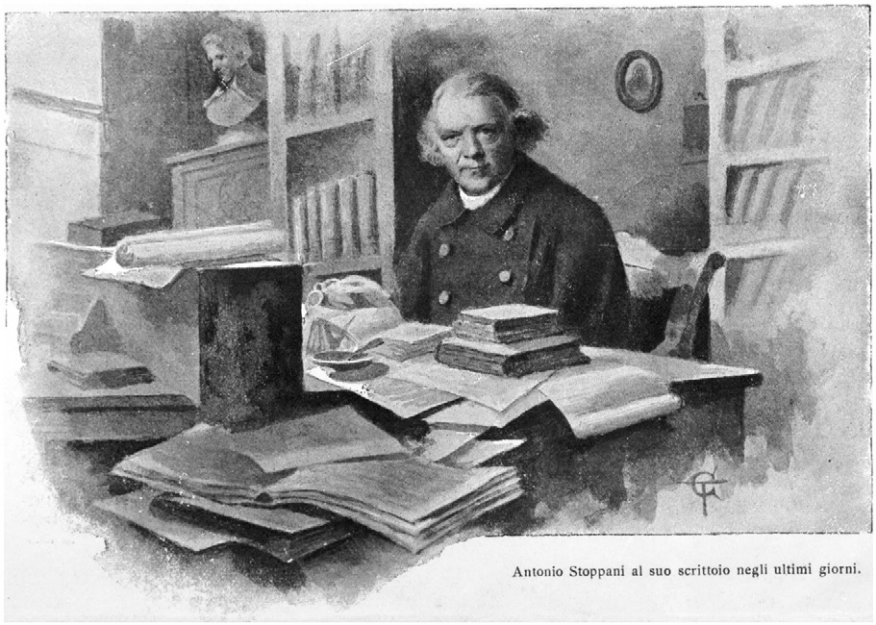

Figure 1. Antonio Stoppani (1824–1891).
From: Il Bel Paese, conversazioni sulle bellezze naturali la geologia e la geologia e la geografia fisica d'Italia. Milano: Casa Editrice L.G. Cogliati.

purely metaphysical concept, but Vernadsky further developed the idea to include human transformation of the biosphere by industrialization and atomic energy. The noosphere would be the third stage in the evolution of Earth, after the geosphere (the inanimate layer) and the biosphere. To refer to the new era corresponding to the noosphere, Vernadsky used Le Conte's "Psichozoic".

The term "Atomic Age" was introduced by the Lithuanian-American journalist William Lawrence in 1946 after the first nuclear explosions. The "Atomic Age" was not intended as a new unit of the GTS, but only as a historical phase. More recently, in 1988, the Armenian geological engineer George Ter-Stepanian argued that the current technological development of humankind was important enough to define a new geological period, following the Quaternary, which he called "Technogene" or "Quinary". Few years later, in 1992, the American historian and priest Thomas Berry proposed that the human misuse of technology will end at some point and will be followed by a new era, the "Ecozoic", in which humans and Earth will live in harmony. The last term proposed before the "Anthropocene", and perhaps its precursor, was the "Anthrocene", introduced by the American journalist Andrew Revkin in 1992.

In summary, there are several, well-documented precursors of the "Anthropocene", but, curiously, only this term has survived as a candidate for a new potential geological unit.

The "Anthropocene" as a new geological epoch

This leads us to one of the more prevalent misconceptions about the "Anthropocene" regarding its current status as a formal epoch of the GTS. Many people, including many scientists, believe that the "Anthropocene" is already an official epoch, but this is far from true. Similar to the Periodic System of Elements in chemistry, the global standard reference for stratigraphic units is the International Chronostratigraphic Chart (ICC), which contains the hierarchical classification of eras, periods, epochs, and so on. To formally define a new unit of the ICC, several requirements need to be fulfilled. The new unit must be based on the existence of a rock body (the stratotype), which differs from underlying rocks and defines a clear stratigraphic boundary, called the Global Stratotype Section and Point (GSSP) or the "golden spike". Such a GSSP must be the local expression of a global phenomenon. For example, the GSSP of the Pleistocene, characterized by the onset of worldwide glaciations, can be defined by changes in particular stratigraphic markers, such as the magnetic properties of rock components, shifts in the isotopic composition of selected elements, or the extinction of marine plankton species, as a consequence of an intense and global cooling that began 2.588 million years ago. Proposals for a new ICC unit should be submitted to the International Commission on Stratigraphy (ICS) for approval and the International Union of Geological Sciences (IUGS) for ratification. In the case of the "Anthropocene", the proposal is currently being prepared by the Anthropocene Working Group (AWG), led by the British geologist Jan Zalasiewicz from the University of Leicester, which brings together the most active defenders of the "Anthropocene" as a new epoch of the ICC, including Paul Crutzen [4]. The AWG was created in 2009 and plans to submit a proposal to the ICS in a couple of years. Why does it take so long?

Characterizing the human impact on Earth based on a single worldwide event and its corresponding imprint in the geological record is not easy. In the original definition [1], the onset of the "Anthropocene" was placed in the second half of the 18th century at the beginning of the industrial revolution. The rationale was that industrialization represents the end of agriculture as the dominant economic activity, deeply changed human lifestyle, and generated a new economic order. The use of fossil fuels increased the available energy by 40 times between 1800 and 2000, which triggered a 50-fold production growth and an increase of the human population from one to six billion people. Atmospheric CO_2 concentration increased from about 280 to 380 ppm during the same period.

The most dramatic change occurred after World War II, during a phase known as the "great acceleration", when all indicators of human activity experienced an amazing growth. Human population increased by 3 billion in only 50 years and economic production multiplied by 15. The number of motor vehicles increased from 40 to 700 million, while petroleum consumption increased 3.5 times. Industrialization also led to the concentration of the human population in big cities and the humanization of nearly half of the terrestrial surface. Biodiversity depletion accelerated and atmospheric radioactivity increased due to

nuclear detonations, which were not abolished until 1996.

The geological imprints of industrialization are numerous and varied, especially in lake and sea sediments and the polar ice accumulated during the past ~70 years. Potential stratigraphic markers for the "Anthropocene", as defined by Crutzen and Stoermer, are "fly ashes" form fossil fuel combustion, which accumulated in sediments and ice sheets. Another signature is the presence of radioactive isotopes created by nuclear explosions: plutonium ($^{239+249}$Pu), lead (^{210}P), or cesium (^{137}Cs). Other possible markers are shifts in the composition of fossil assemblages in lake sediments as a result of drastic changes in aquatic communities owing to fertilizer runoff from agriculture, especially in the northern temperate countries. Acidification of lakes and oceans has also left its fossil imprint on sediments. Another potential stratigraphic marker are plastics and other synthetic materials, which did not exist before industrialization.

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Other scholars, led by the American paleoclimatologist William Ruddiman, argue that the "Anthropocene" began with the expansion of agriculture 8,000 to 6,000 years ago, known as the "Neolithic revolution". The main consequences were the replacement of original vegetation, which affected biodiversity, and the disruption of global biogeochemical cycles. The "Neolithic revolution" also caused a drastic change in human societies from nomadic hunter–gatherer groups to permanent settlements, which developed into cities. The stratigraphic markers would be the occurrence of pollen of cultivated plants, fossils of domestic ruminants, or human tools in the sedimentary rocks formed in those dates. Other markers proposed by Ruddiman are CO_2 and methane concentrations in the atmosphere, which began to increase 8,000 and 5,000 years ago, respectively, as documented in polar ice sheets. Ruddiman explained the CO_2 increase as the consequence of burning forests to make way for fields. The increase of methane may have been caused by rice cultivation, which requires permanently flooded terrains thus favoring anoxic conditions and methane production.

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Others have proposed even earlier events to define the "Anthropocene": for example, the worldwide extinction of large mammals between 50,000 and 10,000 years ago. The causes for this disappearance of about half of all large mammal species from most continents, except Africa, are still debated. Some believe that this megafauna was not able to adapt to warmer climates after the last glaciation, while others argue that they fell victim to human hunting. Whatever the cause, their extinction would have resulted in a global biological reorganization changing the composition and functioning of most ecosystems. The stratigraphic markers would be the joint accumulations of fossils and hunting tools observed in a number of rocks from this age. Another proposal places the onset of the "Anthropocene" with the discovery of America, which has triggered a global biotic mixing and reorganization of the biosphere [5]. Another consequence was the significant reduction of the American population—from about 50–60 million people in 1492 to six million in 1650—as a consequence of wars, slave trading, starvation, and diseases. According to the ecologist Simon Levis and the climatologist Mark Maslin, this would have reduced agriculture and associated deforestation and favoured the recovery of more than 50 million hectares of forests and savannas.

All these possibilities and others were analyzed by the AWG during the 35th International Geological Congress held at Cape Town in August 2016. The AWG agreed on locating the onset of the "Anthropocene" in 1945 and suggested that the stratigraphic marker could be the plutonium generated by atomic explosions. They are now looking to fit the stratotype and GSSP with ICS rules, which is expected to be accomplished in 2–3 years.

Critiques of the "Anthropocene"

The AWG procedures and the outcome have received scientific criticism. Some argue that the procedure is incorrect: The definition of a new unit should come from a stratigraphic need, that is, from the existence of a new rock body and a distinct GSSP, whereas the AWG is trying to define a new stratigraphic unit based on a historical concept using a chronological benchmark. Defined this way, the "Anthropocene" is beyond the scientific scope, because is not an evidence-based concept. Another point is that the decision to place the onset of the "Anthropocene" in 1945 significantly reduces the probability of finding the desired stratotype. According to the AWG, these would be lacustrine and marine sediments, polar ice sheets and calcareous skeletons, such as corals and speleothems. Thus, the stratigraphic markers of the "Anthropocene" would appear only in a thin and fragile layer deposited during the last ~70 years. This turns the idea of the "Anthropocene" into a prospect for the future, in the hope that these thin layers will remain and keep growing until they can be unequivocally recognized by future geologists. Such concept cannot be a stratigraphic target of study, however, as stratigraphy is concerned with the past. Recently, the members of the AWG have addressed these and other scientific criticisms but their position remains essentially the same [6,7].

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Other critics emphasize the socio-political aspects: The American geologists Stanley Finney and Lucy Edwards argue that the formalization of the "Anthropocene" as a new geological epoch follows political, rather than scientific reasons and that the ICS should not take scientific decisions under political pressure [6]. This is not dismissed by the AWG members [7], many

of whom believe that human impact on Earth should be formally recognized if only for society and governments to be aware of it. Under such circumstances, ICS/IUGS members fear that an eventual rejection of the proposal, even based on strict scientific criteria, might be unpopular and viewed as compliance with those who exploit the planet as if its resources and recovery capacity were unlimited. For example, Stanley Finney, who is a member of the IUGS executive committee, claims to feel "like a lighthouse with a huge tsunami wave coming at it" under such situation. Ideally, the eventual formalization of the "Anthropocene" is a scientific issue and should be decoupled from environmental policy matters. The roots of Earth's current exploitation should not be sought in academic affairs but in the dominant economic system based on the utopia of unlimited growth.

The future of the "Anthropocene"

It seems clear that humanity is changing the Earth and that this time span is worth a specific term, as other historical phases. But defining a new geological epoch, as the AWG pursues, is a different undertaking and should be based on stratigraphic needs and rules. Some have therefore proposed using "Anthropocene" as a historical term without any geological meaning, which has fostered, in part, the spectacular expansion of the word. However, the termination "-cene" is reserved for the formal geological epochs of the Cenozoic era and, therefore, "Anthropocene" implicitly refers to a geologic epoch. For similar reasons, a historical name free from stratigraphic burden should not contain the suffixes "-zoic" or "-gene" either [8].

Finally, one could also speculate about the "Anthropocene" in light of the possible future that awaits our species, which is rarely considered in this context. In their introduction of the term, Crutzen and Stoermer wrote that the incoming of the "Anthropocene" could only be prevented by a global catastrophe—massive volcanic eruptions, a nuclear war, asteroid impacts, a glaciation, or a socio-ecological collapse caused by our own stupidity—that eliminates or significantly reduces the human population. This opens a more philosophical debate about how long humankind will persist on this planet and shape it. If we were indeed permanently—whatever this means—influencing the Earth, as many people take for granted [9], the "Anthropocene" or any other unit with the prefix "anthropo-" would be the last unit of the GTS. Perhaps it is worth then to upgrade this unit to a higher stratigraphic rank, such as the "Anthropozoic" proposed by Stoppani almost a century and a half ago.

The end of the "Anthropocene"

From an evolutionary perspective, there is no reason to assume that species, *Homo sapiens* in particular, are eternal. Indeed, the geological record shows us that species end up being extinct at one time or another. Our extinction, however, must not necessarily be catastrophic; there are other ways to become extinct as a species while leaving genetic legacy in the form of one or more descendant species [10]. Whatever the case, our extinction as a species would mark the end of the "Anthropocene" or the "Anthropozoic", but the Earth and its biosphere will continue its travel through space and time. The issue of an "Anthropocene", the GTS, and the whole stratigraphic framework, as human constructions, would no longer exist if our descendant species were no longer interested in stratigraphic affairs.

> *"... our extinction as a species would mark the end of the "Anthropocene" or the "Anthropozoic", but the Earth and its biosphere will continue its travel through space and time."*

In the absence of a total extinction of humankind, our influence on Earth and the corresponding stratigraphic imprint may disappear or become negligible after a drastic reduction in the human population and/or a change in our relationship with the planet. The "Anthropocene" or "Anthropozoic" would end with ourselves on board and a new geologic epoch/era about to begin, assuming that human societies still care about stratigraphy. Yet, such a change of the human population or lifestyle seems unlikely in the current political and economic scenario.

Among the possible cataclysms mentioned by Curtzen and Stoermer, the only predictable change that could drastically reduce human population is the incoming of the next glaciation. Since the beginning of the Pleistocene, the Earth has undergone more than 40 glaciations that consisted of an expansion of the polar ice sheets accompanied by the extension of mountain glaciers worldwide and intense global cooling. Each glaciation has been followed by a warmer interglacial phase. These glacial/interglacial phases are governed by astronomical cycles of the Earth's movements around the Sun. The more recent glaciations occurred at a 100,000-year frequency with interglacial phases lasting between 10,000 and 30,000 years. The last glaciation reached its maximum some 20,000 years ago and affected large parts of Europe and North America, which were under several kilometers deep ice sheets. Most of Europe was covered by tundra and cold steppes with forests only on the southern peninsulas (Iberia, Italy and Greece). At present, we are in the Holocene interglacial that began 11,700 years ago.

Another glaciation, if it happened today, would drastically reduce Earth's population, especially in the Northern industrialized countries, which could cause a global social and economic collapse. Models based on the observed Pleistocene cycles estimate that the next glaciation could start between 1,500 and 10,000 years from now and reach minimum temperatures and, hence, the maximum glacier extent, 60,000 years from now. If the next glaciation ends the influence of mankind as a major geological force, as suggested by Crutzen and Stoermer, the "Anthropocene" would have been a phase of some 10,000 years during the current interglacial and the definition of a new geological epoch would not be necessary. In other words, an "Anthropocene" would make sense only if the current glacial–interglacial cycle is disrupted. Some researchers, Ruddiman among them, believe that anthropogenic global warming will not stop in the near future and thereby postpone the next glaciation. In that case, the physical evidence for the "Anthropocene" would keep accumulating in rocks for the benefit of eventual future geologists.

In summary, for the "Anthropocene" to become a reality, the glacial–interglacial cycle must be interrupted by anthropogenic forcing. If predictions about the next glaciation are correct, we should still wait one or more millennia (40 or more generations) for an answer. If a natural or

anthropogenic global catastrophe annihilates humankind in the meantime, the problem disappears with us. If we evolve into other species, the answer will depend on their eventual interest in geology and the GTS. Therefore, in the present state of knowledge, it is not possible to predict whether the "Anthropocene" will be a new geological epoch/era—probably the last stratigraphic unit of the GTS—or an unnecessary term and concept. Time will tell.

Conflict of interest

The author declares that he has no conflict of interest.

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