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Viewpoint

# The Palaeoanthropocene – The beginnings of anthropogenic environmental change

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ABSTRACT

As efforts to recognize the Anthropocene as a new epoch of geological time are mounting, the controversial debate about the time of its beginning continues. Here, we suggest the term *Palaeoanthropocene* for the period between the first, barely recognizable, anthropogenic environmental changes and the industrial revolution when anthropogenically induced changes of climate, land use and biodiversity began to increase very rapidly. The concept of the Palaeoanthropocene recognizes that humans are an integral part of the Earth system rather than merely an external forcing factor. The delineation of the beginning of the Palaeoanthropocene will require an increase in the understanding and precision of palaeoclimate indicators, the recognition of archaeological sites as environmental archives, and inter-linking palaeoclimate, palaeoenvironmental changes and human development with changes in the distribution of Quaternary plant and animal species and socio-economic models of population subsistence and demise.



## 1. The Anthropocene – climate or environment?

Eleven years after Crutzen (2002) suggested the term Anthropocene as a new epoch of geological time (Zalasiewicz et al., 2011a), the magnitude and timing of human-induced change on climate and environment have been widely debated, culminating in the establishment of this new journal. Debate has centred around whether to use the industrial revolution as the start of the Anthropocene as suggested by Crutzen, or to include earlier anthropogenic effects on landscape, the environment (Ellis et al., 2013), and possibly climate (Ruddiman, 2003, 2013), thus backdating it to the Neolithic revolution and possibly beyond Pleistocene megafauna extinctions around 50,000 years ago (Koch and Barnosky, 2006). Here, we appeal for leaving the beginning of the Anthropocene at around 1780 AD; this time marks the beginning of immense rises in human population and carbon emissions as well as atmospheric $CO_2$ levels, the so-called "great acceleration". This also anchors the Anthropocene on the first measurements of atmospheric $CO_2$, confirming the maximum level of around 280 ppm recognized from ice cores to be typical for the centuries preceding the Anthropocene (Lüthi et al., 2008). The cause of the great acceleration was the *increase* in burning of fossil

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fuels: this did not begin in the 18th century, indeed coal was used 800 years earlier in China and already during Roman times in Britain (Hartwell, 1962; Dearne and Branigan, 1996), but the effects on atmospheric $CO_2$ are thought to have been less than 4 ppm until 1850 (Stocker et al., 2010). The Anthropocene marks the displacement of agriculture as the world's leading industry (Steffen et al., 2011).

However, the beginning of the Anthropocene is more controversial than its existence, and if we consider anthropogenic effects on the environment rather than on climate, there is abundant evidence for earlier events linked to human activities, including land use changes associated with the spread of agriculture, controlled fire, deforestation, changes in species distributions, and extinctions (Smith and Zeder, 2013). The further one goes back in time, the more tenuous the links to human activities become, and the more uncertain it is that they caused any lasting effect.

The proposition of the Anthropocene as a geological epoch raises the question of what defines an epoch. To some extent this is a thought experiment applied to a time in the far future – the boundary needs to be recognizable in the geological record millions of years in the future, just as past boundaries are recognized. This requires changes of sufficient magnitude that can be accurately dated. It is interesting to note that the recent definition of the beginning of the Holocene with reference to ice cores (Walker et al., 2009) fails the criterion of being recognizable well into the future because of the geologically ephemeral nature of ice.

Some geological boundaries are characterized by distinct geochemical markers; for example, the iridium anomaly at the Cretaceous–Neogene boundary, which is thought to have been caused by a meteorite impact. The Anthropocene will leave numerous clear markers including synthetic organic compounds and radionuclides as well as sedimentological memories of sudden $CO_2$ release and ocean acidification (Zalasiewicz et al., 2011b). Many older geological boundaries were defined by disjunctures in the fossil record marked by first appearances or extinctions (Sedgwick, 1852). However, the age of these has changed with improvements in radiometric age dating; for example, the beginning of the Cambrian has moved by 28 million years since 1980. There is abundant evidence that we are currently experiencing the Earth's sixth great mass extinction event (Barnosky et al., 2011), which will be another hallmark of the Anthropocene. The changes that mark the beginning of the Anthropocene are certainly changes of sufficient magnitude to justify a geological boundary (Steffen et al., 2011), whereas the gradual or small-scale changes in regional environments at earlier times were not.

## 2. The Palaeoanthropocene

The term *Palaeoanthropocene* is introduced here to mark the time interval before the industrial revolution during which anthropogenic effects on landscape and environment can be recognized but before the burning of fossil fuels produced a *huge crescendo* in anthropogenic effects. The beginning of the Palaeoanthropocene is difficult to define and will remain so: it is intended as a transitional period, which is not easily fixed in time. We emphasize that we do not intend it to compete for recognition as a geological epoch: it serves to delineate the time interval in which anthropogenic environmental change began to occur but in which changes were insufficient to leave a global record for millions of years. Although it covers a time period of interest to many scientific disciplines stretching from archaeology and anthropology to palaeobotany, palaeogeography, palaeoecology and palaeoclimate, its beginning is necessarily transitional on a global scale because it involves changes that are small in magnitude and regional in scale. The history of human interference with the environment can be represented on a logarithmic timescale

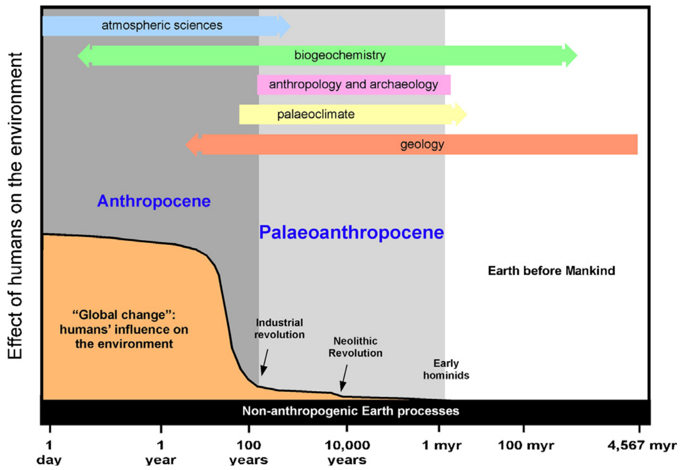


**Fig. 1.** Plotting the history of the Earth on a logarithmic scale gives three approximately equal sections for the Anthropocene, the Palaeoanthropocene and anthropogenically unaffected Earth processes. The Palaeoanthropocene is a period of small and regional effects that are more difficult to define and are currently hotly debated. It is also a time for which the research tools of several scientific disciplines overlap: the integration of results from all these disciplines will be essential to improve our understanding of processes in the Palaeoanthropocene.

(Fig. 1), resulting in three approximately equal areas. In the Anthropocene, major changes (orange) have been imposed on natural element cycles (black bar) that were typical of pre-human times. The Palaeoanthropocene includes the Holocene (beginning 11,700 years ago) and probably much of the Pleistocene (2.58 Ma), and may stretch from about the time of the first appearance of the genus *Homo* until the industrial revolution (Ruddiman, 2005). The arrows in Fig. 1 show the timescales normally considered by various scientific disciplines, emphasizing that only their integration can provide a complete picture. Anthropogenic influences on the environment taper out towards the beginning of the Palaeoanthropocene and get lost in the uncertainties of age determinations. The transition into the Anthropocene is much sharper, involving order of magnitude changes in a short time. The Palaeoanthropocene may seem to largely coincide with the Pleistocene and Quaternary, but these are defined stratigraphically without reference to the environmental effects of humans (Gibbard et al., 2010). Thus, the Palaeoanthropocene should not be anchored on any unit of the geological timescale, but instead be used to emphasize the as yet uncertain period in which humans measurably affected their environment.

Human activities have always been interdependent with the functioning of natural processes. Climatic and environmental changes probably caused major migrations of humans throughout human prehistory (De Menocal, 2001; Migowski et al., 2006), and conversely, the distribution of plants and animals has been strongly affected by human impacts on the environment (Parmesan, 2006). It is important to view humans as an integral part of the Earth System in order to adequately understand inter-relationships and feedbacks between the Earth and humankind. The social perception of the environment and cultural behaviour are a crucial part of systemic interaction. In order to fully understand the transition to the Anthropocene, it is therefore essential to include human culture and its management of landscapes and material cycles into the Earth System concept.

There are several reasons for the diffuse beginning of the Palaeoanthropocene, particularly (1) limitations on the availability of environmental archives identifying events so far in the past; (2) the dampening of signals by the gradual saturation of reservoirs; and (3) the local to regional spatial scale at which these events occurred: populations grew gradually, and new technologies were introduced at different times from place to place.

Relatively little information has yet been extracted from natural archives in Palaeolithic and earlier times. For example, there may be a causal relationship between the arrival of humans and the extinction of Australian megafauna (Brook et al., 2007), but this is currently based on remarkably few localities that demonstrate the temporal coexistence of humans and now extinct species (Wroe and Field, 2006; Field et al., 2013). Landscape burning may have been an important intermediary process (Bowman, 1998). Humans and fire have always coexisted, but the deliberate use of fire may have caused the first appreciable anthropogenic effects on ecology. The habitual use of fire extends back further than 200,000 years (Karkanas et al., 2007) and possibly to almost 2 Ma (Bowman et al., 2009). However, exact dating is hampered by the currently high cost of precise $^{14}C$ dating, which restricts the number of age determinations, as well as the temporal restriction of $^{14}C$ to later periods. Further discoveries of fossils and archaeological remains will improve the temporal precision.

The dampening of signals have prevented thousands of years of wood burning and centuries of fossil fuel usage from being detectable as a significant increase in atmospheric carbon because other environmental carbon sinks had to be saturated before the surplus could be registered in the atmosphere. This is a recurring relationship between geochemical element sinks and atmospheric composition: the major rise of atmospheric oxygen in the early Proterozoic did not immediately follow the biogenic production of oxygen, but had to await the saturation of reduced geological formations before free oxygen could be released. Prior to this, banded iron formations and reduced paleosols dominated (Klein, 2005; Rye and Holland, 1998), to be replaced by oxygenated sediments (red beds) once the atmosphere became oxygenated. Geological processes are very slow, but the element reservoirs are enormous, allowing the potential to buffer anthropogenic increases in emissions. This may appear to render these increases harmless for a given period, but the exhaustion of buffers may lead to tipping points being reached with potentially grave consequences for humankind.

Scales in space and time form perhaps the most important distinction between the Palaeoanthropocene and the Anthropocene. Gas mixing rates in the atmosphere can be considered immediate on historical and geological time scales, and can therefore result in global changes. In contrast, the effects that humans have on their environment take place on a local scale, and these spread to regional events that will not immediately have global repercussions. Understanding the Palaeoanthropocene will require an *increased emphasis on more restricted temporal and spatial scales*. The concept of the Anthropocene has commonly been associated with *global* change, whereas Palaeoanthropocene studies must concentrate on regional issues. Regional studies may deal with human ecosystems as small as village ecosystems (Schreg, 2013). Models of future climate change with regional resolution will also become more important, as local extremes are predicted in areas of high population density, such as the eastern Mediterranean (Lelieveld et al., 2012). For this reason, the beginning of the Palaeoanthropocene should not be assigned a global starting date, but instead is time-transgressive (Brown et al., 2013). It dissipates into a number of regional or local issues the further one moves back in time, varying with the history of each local environment and human society. When it comes to defining the beginning of anthropogenic effects on the environment, time appears to fray at the edges.

## 3. Studying the Palaeoanthropocene

The Palaeoanthropocene involves the interaction of humans with their environment, and so studying it is an interdisciplinary challenge encompassing climate, environmental and geological sciences as well as archaeology, anthropology and history, with improvements in one often prompted by viewpoints or methods imported from other sciences. Here, we briefly outline three areas where rapid progress can be expected.

### *3.1. Human subsistence and migration*

The subsistence and migration of humans and their cultures is fundamental to understanding the interdependence between people, their environments and climatic conditions, and yet this is hampered by the scarcity of archaeological sites that can be dated precisely. Fig. 2 illustrates the expansion of farming through Europe, but the reasons, particularly climatic or environmental factors, remain poorly understood. Prehistoric sites with human remains are known from the Palaeolithic, during which arctic species such as reindeer were amongst the main prey (Gaudzinski and Roebroeks, 2000). The emergence of farming is related to the northward retreat of arctic conditions at the end of the last glacial period and thus to climate on a supra-regional scale. There are indications that early Holocene climate fluctuations may have paced the migration of farming populations (Weninger et al., 2009; Gronenborn, 2010, in press; Lemmen et al., 2011). However, the degree to which early farming populations caused measurable increases in greenhouse gases remains controversial (Kaplan et al., 2010; Ruddiman et al., 2011; Ruddiman, 2013).

Food supplies have always played a central role in determining the migration and expansion of human populations in response to environmental and climate changes. Agricultural production of grains and the keeping of livestock gradually spread, leading to important societal changes and to new attitudes to the distribution of resources, stockpiling, territoriality and work distribution, resulting in the first major population increase in human history (Chamberlain, 2006; Bocquet-Appel and Bar-Yosef, 2008). Increasing population density led to new forms of interdependence between humans and nature such as crop failures and floods, which frequently ended in food shortages. Further technological innovations allowed further increases in population, which increased the risk of subsistence crises.

For a great proportion of their history, humans have been immediately dependent on their environment in terms of plants, animals and water supply. Changes in diet can be reconstructed using skeletal remains as a dietary archive and analyzing radiogenic and stable isotopes, trace elements, and ancient DNA (Evans et al., 2006; Haak et al., 2008; Mannino et al., 2011). Radiogenic isotope systems are important in ascertaining the age, migration, geological substrate and diagenesis of bones and thus the relative importance of dietary and environmental factors. Ancient DNA analysis has recently allowed remarkable insights into movements, population mixing and evolution of the human genome (Haak et al., 2005; Burger et al., 2007; Bramanti et al., 2009; Haak et al., 2010; Brandt et al., 2013), providing a new temporal and spatial resolution for Palaeoanthropocene studies.

### *3.2. Regional palaeoclimate*

A main difference between the Palaeoanthropocene and the Anthropocene is the gradual switch from regional to global scale of anthropogenic influences. In Palaeolithic to Neolithic times, changes were related to fires, land use, and species extinctions, which are regional effects. In palaeoclimate research, the collection of long-term climate information has been emphasized because of the desire to model *global* changes in climate. Many of the archives are marine (e.g. Kennett and Ingram, 1995), which may transmit a dampened signal in which extreme events are removed or minimized, particularly in the older time sections. Despite having more potential on short timescales, detailed continental records are

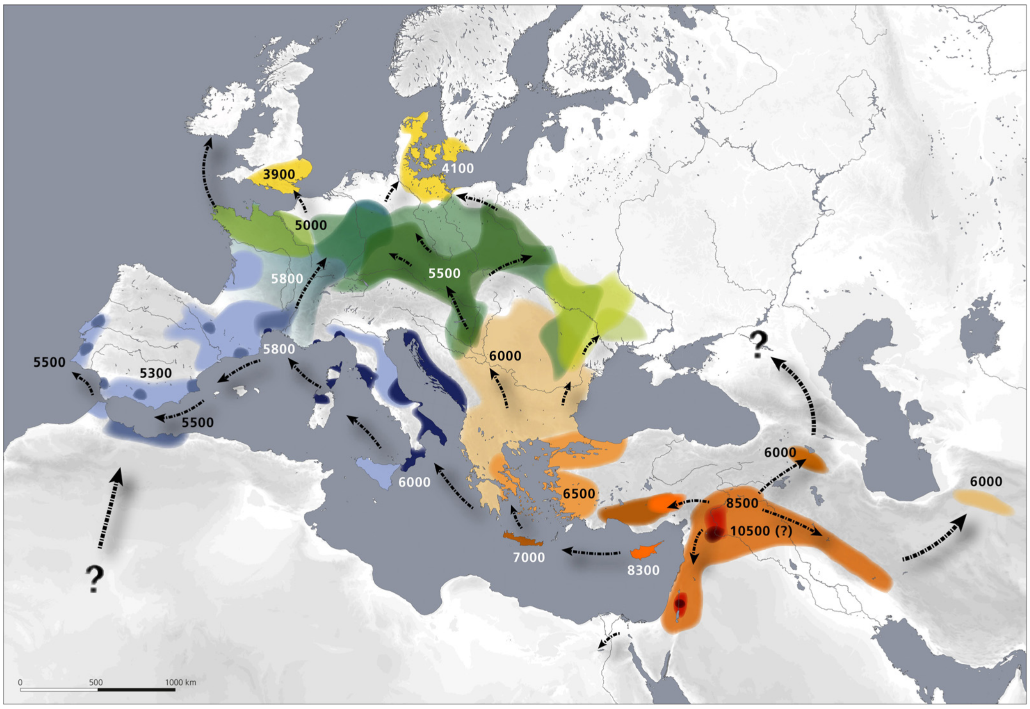


**Fig. 2.** Map showing the distribution of the first farming societies in western Eurasia together with dates for major human migration episodes (in years calibrated B.C.) beginning from the Fertile Crescent, which had a much more temperate climate at the time (after Gronenborn, 2010, in press). Greater temporal resolution and precision and further understanding of the reasons for migration will require input from many scientific disciplines to assess the relative importance of short-scale climate, environmental and species distributions.

commonly used only to derive average temperatures (Sukumar et al., 1993; Farrera et al., 1999). For Palaeoanthropocene climate studies, both regional and short time-scale information is needed to unravel the complex interplay of humans and their environment.

Ocean mixing processes are sluggish on anthropogenic time scales, resulting in dampened signals. Because it is the land on which people live, early land use changes will be recorded in continental archives first, promoting their importance over marine archives. Furthermore, continental archives preserve information on extreme events, permitting cross-referencing with archaeological records.

Periods of weeks to a year incorporate most of the hazards for human sustenance and survival, but are beyond the resolution of many palaeoclimate repositories. Although insignificant when the whole Quaternary is considered, this is the timescale of crop failures and subsistence crises (Büntgen et al., 2011). The integration of several proxies revealing the palaeoclimate of continental regions will increasingly permit annual to seasonal resolution, illuminating extreme natural events that may have been critical triggers for crises and migrations. We currently have only limited understanding of the spatial patterns of temperature, precipitation and drought variations in short-term extreme events and periods of rapid climate change throughout the Quaternary. The high temporal resolution that is becoming available from multiple continental palaeoclimate proxies will enable the closer study of time slices of single seasons to several years (Sirocko et al., 2013).

Speleothems can be dated with unprecedented precision over the last ~650,000 years by U-series methods (Scholz and Hoffmann, 2011) representing a key archive for seamless climate reconstructions. The development of new proxies and archives, such as compound specific isotope ratios in lignin methoxyl groups in wood (Keppler et al., 2007), multi-proxy data derived from continental loess deposits and palaeosols (Sheldon and Tabor, 2009), or Roman aqueduct sinter (Surmelihindi et al., 2013) will further strengthen multi-proxy approaches.

Biomineralisation needs to be considered in assessing past climate variability. Unexpected mismatches between temperature proxies illustrate that we know too little about the mechanisms by which climate and environmental information is recorded. Mineralizing organisms exert specific physiological controls on the minerals they form so that the chemical behaviour of elements and isotopes used for climate reconstruction deviates from that expected in geochemical equilibrium. These "vital effects" (Urey et al., 1951), occur in all living systems, describing an array of species-specific deviations from equilibrium compositions. Some bivalves begin the crystallization process using amorphous calcium carbonate (Jacob et al., 2008, 2011), and amorphous precursor phases appear to be universally involved in biocarbonate and bioapatite formation. This affects the storage of temperature information, which may change during the lifetime of individual organisms (Schöne et al., 2011).

For all palaeoclimate reconstructions, the storage of data from individual proxies in central repositories will improve transparency and provide essential supplements to the publication of large data sets as figures.

### 3.3. Palaeoenvironmental sciences

The clearing of forests to provide agricultural land may have already been widespread more than 3000 years ago (Kaplan et al., 2009), and may have had far-reaching impacts on palaeoecology and the evolution and distribution of plant and animal species. Much earlier, fire was used to control vegetation and may have affected species extinctions (Bowman, 1998; Bowman et al., 2009).

We need to understand how Quaternary evolution would have progressed without the influence of humans. The Quaternary was a hotbed of evolution, and the spread of humans throughout Europe coincided with its re-colonization by plants and animals after the end of the ice age (Comes and Kadereit, 1998; Hewitt, 1999). We also need to assess what the atmospheric composition would have been without human perturbation. This is possible for a number of trace gases such as $CO_2$ and $CH_4$ by analysing bubbles trapped in ice cores, but exceedingly difficult for other potent climate agents such as aerosol particles (Andreae, 2007).

Modelling natural species distributions will further delineate changing ecological conditions, and may identify the beginnings of divergence of biodiversity from natural patterns. Models of niche evolution will integrate climate- and human-induced biological evolution with past environmental change, including dropping the assumption that the ecological requirements of species did not change in the relevant time span (Futuyma, 2010). The projection of ecological niches into the past will be greatly refined by improved palaeoclimate chronologies. Approaches from ecological system theory help to provide new perceptions of sustainability and novel insights into the complex processes of societal collapse and triggering of migrations.

A further development assisting Palaeoanthropocene studies is the treatment of archaeological sites as environmental archives (Bridgland, 2000; Tarasov et al., 2013). Integrated geomorphological, environmental and archaeological studies help to reveal the dimension, intensity and duration of how human societies exploited and changed natural environments and, conversely, how changing natural environments and landscapes provoked the adaptation of land use strategies. Examples are possible feedbacks between the climatically favoured expansion of savanna ecosystems beginning in the late Miocene, the acquisition of fire by early hominids and its influence on human evolution, and the eventual use of fire for landscape management in the late Pleistocene (Bowman et al., 2009).

The recognition of interactions between the regional and global scales is important since land use changes can have global effects (Foley et al., 2005). High-resolution regional data sets on vegetation, environment, climate and palaeoweather (integrating sedimentological and meteorological data; Pfahl et al., 2009) must be combined with models of land use and village ecosystem dynamics to achieve long-term perspectives on causality and complex system behaviour in human–environment systems (Dearing et al., 2010).

In summary, the term Palaeoanthropocene refers to the period from the beginning of human effects on the environment to the beginning of the Anthropocene, which should be reserved for the time after the great acceleration around 1780 AD. The Palaeoanthropocene has a diffuse beginning that should not be anchored on geological boundaries, as it is linked to local events and annual to seasonal timescales that cannot be recognized globally. Progress in Palaeoanthropocene studies can be expected through greater precision in palaeoclimate reconstructions, particularly on continents, and it's coupling with studies of environmental archives, new fossil discoveries, species distributions and their integration into regional numerical models of climate and environment.

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