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Anthropogenic soils are the golden spikes for the Anthropocene

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Abstract

We propose that the Anthropocene be defined as the last *c.* 2000 years of the late Holocene and characterized on the basis of anthropogenic soils. This contrasts with the original definition of the Anthropocene as the last *c.* 250 years (since the Industrial Revolution) and more recent proposals that the Anthropocene began some 5000 to 8000 years ago in the early to mid Holocene (the early-Anthropocene hypothesis). Anthropogenic soil horizons, of which several types are recognized, provide extensive terrestrial stratigraphic markers for defining the start of the Anthropocene. The pedosphere is regarded as the best indicator of the rise to dominance of human impacts on the total environment because it reflects strongly the growing impact of early civilisations over much of the Earth's surface. Hence, the composition of anthropogenic soils is deemed more appropriate than atmospheric composition in providing 'golden spikes' for the Anthropocene.

Keywords

Anthropocene, anthropogenic soils, anthropogenic soil horizons, human footprint

Introduction

The term *Anthropocene*, which was coined at the beginning of this century by the Nobel Laureate Paul J. Crutzen (Crutzen, 2002; Crutzen and Stoermer, 2000), is now widely used by the scientific community. It recognises the current epoch of Earth's history when humankind has joined with the other environmental forces in shaping the planet. When did such an epoch commence? Crutzen placed great weight on atmospheric composition and assumed the origin of Anthropocene to be synchronized with the appearance of the steam engine in the late-eighteenth century. This marks a significant upturn in the burning of fossil fuels, as shown by the composition of the air trapped in the Polar ice sheets and ice caps, corresponding to a sharp increase in carbon dioxide and methane concentrations in the atmosphere.

Although it is unquestionable that the Industrial Revolution ushered in an unprecedented global human impact on Earth (Douglas et al., 2002) that resulted in today's human domination of ecosystems (Sanderson et al., 2002; Vitousek et al., 1997), many parts of the Earth's surface had been already profoundly modified by human activities (Kirch, 2005). Rome 2000 years BP, Baghdad and Chang'an some centuries later, and Beijing, Edo, Guangzhou, and London at the beginning of the Industrial Revolution, already contained more than 1 million people. In Europe alone, at least 20 cities had populations over 100 000, including Amsterdam, Berlin, Lisbon, Madrid, Moscow, Naples, Paris, Rome, St Petersburg, and Vienna (Chandler, 1987; Modelski, 2003). In order to sustain these citizens and the rest of the humankind there had already been major human impacts involving deforestation, grazing, agriculture, construction of roads and harbours, and other related activities. Hence, it is arguable that the Anthropocene began earlier than the mid-eighteenth century.

Still using atmosphere composition as a marker, Ruddiman (2003) proposed the early-Anthropocene hypothesis. This attributes a much earlier rise in atmospheric CO_2 and CH_4 detected in ice cores to human impacts. In particular, 8000 years ago, the CO_2 trend experienced an anomalous increase of up to 20–25 parts-per-million above the previous level. This was explained by Ruddiman (2003) by forest clearance. Dull et al. (2010) show that demographic pressure on tropical forests increased steadily throughout the late Holocene, to peak in the late-fifteenth century, when Europeans arrived and introduced diseases that led to recurrent epidemics and resulted in an unprecedented population crash. These authors argue that the regrowth of tropical forests following the Columbian encounter induced terrestrial biospheric carbon sequestration on the order of 2–5 Pg C, thereby contributing to the documented decrease in atmospheric CO_2 recorded in Antarctic ice cores from about AD 1500 to 1750, which previously had been attributed exclusively to reduced solar irradiance and an increase in global volcanic activity. The CH_4 peak of 250 parts-per-billion, reached at 5000 yr BP, was explained by Ruddiman and Thomson (2001) in terms of the inefficiency of early rice irrigation. Extensive flooded wetlands harbouring numerous weeds would have emitted large amounts of methane while feeding relatively few people.

However, the early-Anthropocene hypothesis remains unproven (see, for example, Ruddiman et al., 2011). At 5000–8000 years ago, the planet sustained a a few million people and was still fundamentally pristine (Boyle et al., 2011). At that time, there were a few organized societies scattered in China, Egypt, the Fertile Crescent and the Indus Valley. Consequently, the impact of humans on the planet must be considered modest, patchy and readily healable by

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nature. On a global scale, early- and mid-Holocene human footprints were very limited (with the possible exception of the atmosphere as envisaged by the early-Anthropocene hypothesis) throughout the major 'spheres' of the Earth, namely the lithosphere, hydrosphere, biosphere and pedosphere.

We therefore argue in this Forum Article, for a more representative start to the Anthropocene between the modern era and the early to mid Holocene. We question the suitability of using atmospheric composition as a marker for the Anthropocene. Instead, we seek a marker that reflects a substantial global impact of humans on the total environment, comparable in scale to those associated with significant perturbations of the geological past (Zalasiewicz et al., 2010a). In addition, we seek a marker that can be recognised in the stratigraphic record; the 'golden spikes' of geologists, also known as global standard stratotype-section and points (GSSPs). These are locations where there are strata successions with clear evidence of a worldwide event, including the appearance of distinctive fossils. Golden spikes are named by working groups within the International Commission on Stratigraphy and then ratified by the International Union of Geological Sciences (Berggren et al., 1995). Once a golden spike is set, that rock remains the boundary of a time period, even if estimates of its age change. The first golden spike was established in 1972 near the town of Klonk (today Czech Republic), where pristine fossils can be found of an extinct marine invertebrate, graptolite. The appearance of this fossil divides the Silurian from the Devonian (Whitfield, 2004). Efforts to provide a more appropriate marker than atmosphere composition on which to characterize the Anthropocene, a marker that follows stratigraphic criteria, are in progress (Price et al., 2011; Zalasiewicz et al., 2011).

The start of the human footprint

Could the Anthropocene have a marker more similar to the rocky strata of geologists than the ice layers, whose faint signals do not directly account for irreversible human-induced impacts on natural landscapes and biotic resources worldwide? Additionally, ice layers, with their sealed contaminated air bubbles lack permanence, because they are prone to be cancelled by ongoing climate warming (Gillett et al., 2011). When did the human footprint become so weighty as to indicate the start of the Anthropocene? It is difficult, perhaps even unrealistic, to identify a Year Zero of the Anthropocene. The human impact on Earth has grown progressively, with few substantial slowdowns.

The human impact started, of course, with the appearance of people but as they were low in number and used to gather undomesticated edible plants and wild animals, the initial impact was negligible. People began representing an important controlling factor of landscape and the environment once they started deforesting and cultivating land. However, their ecological footprint was still confined, for a long time, to relatively small areas of the planet. Ruddiman and Ellis (2009) calculated total land clearance from 7000 to 200 years ago as the result of global population and per-capita land use. The estimated trend rose until 2000 years ago, then flattened out for about 1000 years before increasing again. This could be used to define a plausible starting point of the Anthropocene at *c*. 2000 BP, which roughly coincides with the start of the final phase of Holocene, the Sub-Atlantic.

At the inception of the Christian era, the world was colonized by many well-organized societies, which were shaping the landscape, superimposed on the action of natural events. At this time, the Roman Empire encompassed large portions of Europe, the Middle East and North Africa, in China the classical dynasties were flowering, the Middle kingdoms of India had already the largest economy of the ancient and medieval world, the Napata/Meroitic kingdom extended over the current Sudan and Ethiopia, the Olmecs controlled central Mexico and Guatemala, and the pre-Incan Chavín people managed large areas of northern Peru. In the Roman Empire, for example, much land was cultivated: it is estimated that North African provinces supplied half a million tonnes of wheat, two-thirds of cereals consumed in the capital, Rome (Raven, 1969). This consumption impinged on the pristine landscape of those provinces involved in the production. At that time, Cato the senior and Columella were writing the first systematic textbooks about how to select highly fertile soils and how to manage them for productive purposes. In the Roman Empire, forest clearance occurred at impressive rates for obtaining arable land but also retrieving wood for building ships, cooking food, or heating water in public baths; as a consequence, the Mediterranean basin underwent intensive deforestation (Wertime, 1983; Williams, 2000). Mining for metals was largely required for making weaponry and ordinary tools. The impact of this activity on environments was a dramatic contamination by heavy metals in Europe and surroundings, which peaked in the Roman Period, as assessed in the peat bogs of Belgium and Wales (De Vleeschouwer et al., 2007; Mighall et al., 2009), the lake sediments of Sweden (Renberg et al., 1994), and the ice cores of Greenland (Hong et al., 1996). Contemporaneously, in many other places of the world the human impact was not negligible at all. For example, the Maya lowlands of Guatemala and Belize were undergoing widespread deforestation (Islebe et al., 1996; Pohl et al., 1996), whereas in Mesopotamia (modern Iraq) where the first towns originated around 3.0–3.5 ka BP, arable lands were already made unfertile because of continued irrigation with saline waters (Jacobsen and Adams, 1958).

It should be pointed out that two millennia ago the human-impacted areas were widespread but did not merge across the globe. Large buffering areas still occurred in between (Kaplan et al., 2011). Nonetheless, it is hard to believe that the severe exploitation of natural resources, even if restricted to limited areas, did not have ramifications elsewhere. Examples of expansion of impacts beyond local areas are the cases of pollution by heavy metals from mines of the ancient Romans and the deposition of large quantities of eroded soil material from the deforested areas bordering the Mediterranean Sea (Hughes, 2011; Syvitski and Kettner, 2011).

Anthropogenic soils as golden spikes for the Anthropocene

If we assume that 2000 yr BP is a plausible date for the dawn of the Anthropocene, what are the most reliable stratigraphic markers? We believe that best markers can be found in the pedosphere, the soil mantle that covers most of the ice-free land of the globe. Soils are historical entities that retain information of their climatic and geochemical history. Soil features such as the accumulation of illuvial clay at depth or the cementation of layers by secondary silica or iron oxides can last for centuries or millennia (Richter, 2007), immune to climate changes or natural calamities. Soils are more extensive and permanent than the ice sheets and ice caps of the polar regions. Some soil features are peculiarly of anthropic origin and hence unequivocally reveal the presence and activity of people: examples include spade or plough marks, the excess of extractable phosphorus from over-fertilization and the occurrence of artefacts. Just based on soil pollution, Zalasiewicz et al. (2010b) proposed that the start of the Anthropocene occurred during World War II, when radioactive fallout branded soils and sediments all over the world. Although this marker is of worldwide extent, soil features other than contamination from radionuclides testify to a much older widespread human disturbance of the environment.

Land levelling, trenching and embankment building for various purposes, organic matter enrichment from additions of

Figure 1. Terra Preta profile in Laguinho, central Amazon. Soil formation started at *c.* 1500 BP and the protruding potsherds are artefactual evidence of the crucial role of human activity as a soil-forming factor (Courtesy of Lilian Rebellato and William I. Woods, University of Kansas)

manure or other waste, organic matter impoverishment due to continued cultivation, and compaction from overgrazing are some of the ways human activity has directly impacted on soils. Selected features are evidences of judicious past management of soils for the purpose of improving their fertility. *Terra Preta de Indio* (Figure 1) are very dark soils of the Amazon Basin made fertile by adding over many years a mixture of charcoal, manure, plant residues and animal bones to otherwise highly weathered infertile soils (Glaser et al., 2001). *Terra Preta de Indio* were created between 550 BC and AD 950, and are estimated to amount to several thousands of square kilometres (Mann, 2000; Woods, 1995). Charcoal-enriched soils very similar and approximately coeval to *Terra Preta de Indio* have been studied in Australia and tentatively called *Terra Preta Australis* (Downie et al., 2011).

Plaggen soils provide another example of the huge human effort expended to increase water retention and nutrient supply of sandy soils developed on marine and fluvial sediments. Such soils have a thick, very dark brown, organic-rich surface horizon formed by long-continued manuring with peat and materials used for livestock bedding, often mixed with faeces and sod. Formation of this layer, which by convention must be thicker than 50 cm, occurred between about 3000 yr BP and the eighteenth century, especially near villages, where agriculture was most intense. Plaggen soils occur in several places worldwide, e.g. the Low Countries (Blume and Leinweber, 2004), Russia (Giani et al., 2004) and New Zealand (McFadgen, 1980).

Terracing is a practice that enabled cultivation of steep terrain by people who could not avail themselves of enough flat land. Where soil was sparse, it was brought in for the artificial terraces from elsewhere. Terrace cultivation has been practiced for centuries in a number of places, e.g. in the Mediterranean basin (Price and Nixon, 2005), New Mexico (Sandor et al., 1990), Meso-America (Borejsza et al., 2008), Peru (Sandor and Eash, 1995), the Philippines (Acabado, 2009), and China (Veeck et al., 1995).

Terra Preta, plaggen soils and terracing are only a few of the numerous examples of substantial domestication of soil resources aimed to improve human welfare. In all of these cases, human activity is the main driving factor of soil morphology and properties. Soils that conserve clear memories of past, substantial, widespread, anthropic interventions on the environment can be rightly considered golden spikes for the Anthropocene in a similar way to the use of natural geological strata for earlier epochs. Such anthropogenic soils are soils markedly affected by human activities, such as repeated ploughing, the addition of fertilizers, contamination, sealing, or enrichment with artefacts (Figures 1 and 2). Human activity is now firmly established as the sixth factor of soil formation. Although human activity is conditioned by cultural characteristics, the impact of people on soils is clearly distinct from that of other organisms (Amundson and Jenny, 1991). Bockheim and Gennadiyev (2000) therefore consider *anthrosolization* as an autonomous soil-forming process, on a par with the other sixteen 'natural' ones they list. Soil-forming processes are sets of physical phenomena and/or (bio)chemical reactions that work together to transform unaltered parent material into soil, and for these authors anthrosolization affects pedogenesis essentially by ploughing, addition of fertilizers, irrigation with sediment- and salt-rich waters, and deep working.

Similar arguments have led to the recognition of human activity in the classification of soils. The World Reference Base for Soil Resources (WRB) (IUSS Working Group WRB, 2006) which is the internationally approved language for classifying soils, already includes among its 32 Reference Soil Groups two characterized by significant human influence: *Anthrosols*, having a plaggic, terric, anthraquic, hortic, irragric or hydragric horizon; and *Technosols*, having in the upper metre at least 20% artefacts or an artificial low permeable layer covering at least 95% of the horizontal extent of soil. In addition to the above mentioned plaggic and the less acid analogous terric horizons, other

Figure 2. Remains of the Etruscan city of Marzabotto, dating to before 2000 BP, were preserved by an anthropogenic soil as memories of the first intense exploitation of this site in Central Italy

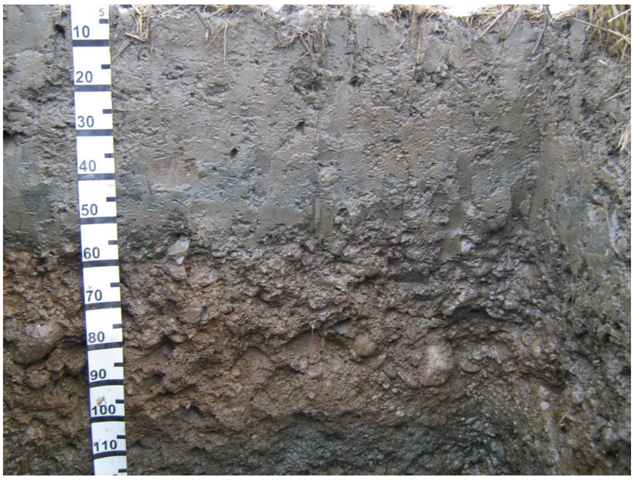

Figure 3. Anthraquic horizon (from the surface to about 55 cm), comprising a puddled layer and a plough pan, in a paddy soil of NW Italy. Here, the Duke of Milan introduced rice cultivation in the fifteenth century. As a consequence of periodic, repeated saturation with groundwater, the soils turned gleyic with redoximorphic colour patterns. In the upper puddled layer, iron and manganese oxides were reduced and either removed or reprecipitated into Fe/Mn(II) minerals, imposing grey colours. Deeper in the profile, the translocated Fe^{2+} and Mn^{2+} precipitated as oxidized and coloured forms, creating mottling in the plough pan visible at intermediate depth. A hydragric horizon (~55–80 cm) occurs below the plough pan, and shows segregations of Fe and/or Mn in the matrix as a result of temporary oxidative conditions. All such redoximorphic features are lasting, indirect evidences of anthropogenic interventions. Scale is in cm

man-made diagnostic horizons are anthric horizons, moderately thick, dark-coloured layers resulting from long-term ploughing, liming, and fertilization; anthraquic horizons, which comprise a puddled layer flooded for part of the year and an underlying plough pan (Figure 3), hortic horizons (from Latin *hortus*, garden), resulting from deep cultivation, intensive fertilization and/or long-continued application of human and animal wastes, irragric horizons, which build up gradually through continuous application of irrigation water with substantial amounts of sediments, and hydragric horizons (Figure 3), which are subsurface horizons associated with wet cultivation of rice.

Anthropogenic soils or Anthrosols are recognized at the highest hierarchical level also in other national classifications, e.g. those of Russia (Shishov et al., 2001), Australia (Isbell, 1996), and China (Shi et al., 2005). In the latter, the Anthrosols dominate, by far, all the other 11 Soil Orders, accounting for one-fifth of the approximately 2500 soil series and covering roughly one-tenth of the Chinese territory. The widely used Soil Taxonomy (Soil Survey Staff, 2010), the classification system of the USA, although recognising similar diagnostic horizons and features of the WRB, does not still assign the highest rank (Order) to Anthropogenic soils and confines them to subordinate levels. However, the demand to emphasise the influence of humans on soil formation is now pressing the process of updating the Soil Taxonomy, and an International Board called ICOMANTH (http://clic.csec.vt.edu/icomanth/) has been set up for the purpose of giving due recognition to anthropogenic soils.

Conclusion

We question whether the Anthropocene really started in the late-eighteenth century, and whether atmosphere composition should be used as a marker for the dawn of the Anthropocene. The Anthropocene is, by definition, the period when human activity acts as a major driving factor, if not the dominant process, in modifying the landscape and the environment.

It is undeniable that in the late-eighteenth century the Earth had already largely experienced a marked human footprint throughout the Earth's 'spheres'. The beginning of the Anthropocene must therefore be placed earlier. However, change in atmosphere composition is unsuitable as a criterion to define the start of the Anthropocene because it does not adequately reflect the global extent of human impacts on the total environment across the Earth's surface. If atmospheric composition did change substantially in the early to mid Holocene, as envisaged by the 'early-Anthropocene hypothesis', this makes it an unsuitable marker because this would suggest significant human-induced changes when the human population was small and its impact on the total environment of Earth was minor.

A more appropriate witness to the birth of the Anthropocene is therefore required. Here, we advance the hypothesis of 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. In our view, the pedosphere is undoubtedly the best recorder of such major human-induced modifications of the total environment. Anthropogenic soils in general and anthropogenic soil horizons in particular are recalcitrant repositories of artefacts and properties that testify to the dominance of human activities. Hence, such soils are considered appropriate to play the role of golden spikes for the Anthropocene.

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