# The stratigraphic status of the Anthropocene

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## Abstract

The term Anthropocene was coined to describe the present geological epoch, in which human activity dominates many of the processes acting on the surface of the Earth. The expression has been widely adopted, but remains informal and lacks precise definition.

There have been several attempts to establish formal stratigraphic markers to define the start of the Anthropocene. Most recently, Certini and Scalenghe (2011) have argued that the best markers are anthropogenic soils and that these may be used to identify the base of the Anthropocene in stratigraphic sequences. Unfortunately, soils fail to meet many of the criteria required for the establishment of stratigraphic 'golden spikes'. Their preservation potential is poor, many stratigraphically important environments do not experience pedogenesis and anthrosols do not always provide the stratigraphically lowest marker of human impact. In addition, there are practical and theoretical difficulties in defining the base of anthrosols and thus in identifying the start of the Anthropocene.

More generally, the worldwide diachroneity of human impact makes it impossible to establish a single chronological datum for the epoch, raising questions about the value of stratigraphic methods in defining the base of the Anthropocene. More significantly, much of the work undertaken on the Anthropocene lies beyond stratigraphy, and a stratigraphic definition of this epoch may be unnecessary, constraining and arbitrary. It is not clear for practical purposes whether there is any real need for a golden spike at the base of the Anthropocene. The global stratigraphic approach may prove of limited utility in studies of human environmental impact.

## Keywords

Anthropocene  anthrosols  global stratotype section and point  golden spike  stratigraphy

## Introduction

The term Anthropocene was coined in 2000 by Crutzen and Stoermer to describe the present geological epoch[1], in which human activity has dominated many of the processes acting on the surface of the planet. The expression has been widely adopted (see, for example, Crutzen and Steffen, 2003; Zalasiewicz et al., 2008; Ruddiman et al., 2011; Williams et al., 2011) and its status is currently being assessed by the Anthropocene Working Group of the Subcommission on Quaternary Stratigraphy (International Commission on Stratigraphy). Meanwhile, its usage remains informal and the term awaits precise definition. One of the concerns to be dealt with before any stratigraphic unit can be formally established is its chronology. In particular, it is essential that the starting point of the new epoch be determined. There are two ways in which this may be done. In the case of the Phanerozoic, the base of every period, epoch and age is, or soon will be, defined by a global stratotype section and point (GSSP), the latter forming a so-called 'golden spike' within a stratotype section (Gradstein et al., 2004a). The spike marks the point at which a critical change (usually biostratigraphic) occurs within an internationally accepted stratigraphic sequence. This point is taken to represent the boundary between intervals of geological time, with the start of each chronostratigraphic unit located above an isochronous surface at the point of change (Remane et al., 1996; Gradstein et al., 2004b, 21).

In the case of the Precambrian, by contrast, stratigraphy is classified on the basis of linear time, with the base of each Precambrian eon, era and period assigned a numerical age (Gradstein, 2004, 3; Robb et al., 2004). The Precambrian timescale is thus chronometric rather than chronostratigraphic (Gradstein et al., 2004b, 21).

Attempts to define the base of the Anthropocene have focussed on the identification of stratigraphic markers of human impact. At first sight, this is surprising since it might be imagined that numerical dating of the recent past would be straightforward and that an approach similar to that used until very recently to define the start of the Holocene might be employed (Walker et al., 2009, 6). In reality, dating the recent past at a resolution commensurate with the timescales involved is far from easy (Gale, 2009a). Possibly more importantly, the diachronous nature of human impact on the Earth means that it is impossible to offer a single date that characterises the initiation of human disturbance at all points on the planet's surface.

Initially, the start of the Anthropocene was assigned to the latter part of the 18th century when the Earth began to experience the environmental changes wrought by industrialisation (Crutzen and Stoermer, 2000; Crutzen, 2002). The base of the epoch was thought to be marked by an increase in carbon dioxide and methane in ice cores and by changes in biological assemblages in lake sediments. Zalasiewicz et al. (2008, 7) broadly accepted this interpretation, recognising the stratigraphic potential of the rise in atmospheric carbon dioxide levels above background values. However, they proposed two additional signals that might be employed to mark the base of the Anthropocene: the mid-

20th century deposition of artificial isotopes associated with atmospheric nuclear weapons testing and the fallout markers resulting from the eruption of Mount Tambora in Indonesia in April 1815. These represent well-dated and widespread event markers (Gale, 2009b), but neither records the start of the environmental changes consequent upon human impact. Significantly too, they represent chronometric rather than chronostratigraphic indicators.

By contrast, Ruddiman and his colleagues argued that the start of the Anthropocene may be found in the early part of the Holocene, thousands of years prior to industrialisation. They proposed two stratigraphic markers to represent the base of the epoch. First, there is the rise in atmospheric methane values in ice cores that took place around 5000 years ago. This is thought to have resulted from the spread of irrigated rice agriculture through the tropics (Ruddiman and Thomson, 2001; Ruddiman, 2003). Secondly, there is the increase in atmospheric carbon dioxide concentration in ice cores that occurred perhaps 8000 years ago. This is considered to have been caused by pre-industrial land clearance. Not surprisingly, there is considerable debate surrounding the question of the initiation of the Anthropocene and many workers interpret these early changes in atmospheric composition as a product of natural forcing mechanisms (see, for example, Ruddiman et al., 2011).

## Soils as markers of the base of the Anthropocene

Dissatisfaction with these suggestions led Certini and Scalenghe (2011) to seek an indicator of the base of the Anthropocene that is recognisable in the stratigraphic record and that is capable of acting as a golden spike. They questioned the suitability of changes in atmospheric composition as indices of the initiation of human impact and instead sought a marker that reflects '… a substantial global impact of humans on the total environment …' (p. 1270). They concluded that the best markers are anthropogenic soils; that is, soils markedly affected by human activities.

In the discussion that follows we leave aside any consideration of whether the pedosphere truly represents '... the best indicator of the rise to dominance of human impacts on the total environment ...' (Certini and Scalenghe, 2011, 1269). Instead, we focus on the stratigraphic role of soils and particularly on their use as golden spikes in stratigraphic sequences.

We define soils here (following, in part, Soil Survey Staff, 1999, 9) as components of the regolith that form on the land surface in association with the presence of rooted plants. Soil profiles are characterised by more-or-less well defined horizons that are distinguishable from the parent material as a result of additions, losses, transfers and transformations of energy and matter vertically through the profile.

Perhaps the most important requirement of a GSSP is that it should be suitable for global correlation. That is, that it should be recognisable outside the GSSP locality and locatable in other sequences (Remane, 2003, 12; Gradstein et al., 2004b, 23). Yet, over most of the Earth's surface, soil-forming processes cannot occur, soils cannot form and it is impossible

to employ soils as stratigraphic markers. By choosing soils as the marker of the base of the new epoch, environments such as oceans and ice masses are effectively excluded from participation in the Anthropocene stratigraphic project. Yet the oceans and the ice caps possess some of the most significant records of the environmental changes consequent upon human activity.

Even if we restrict our attention to the terrestrial landscape, many of those environments in which detailed stratigraphic records of human impact are preserved are ones in which soil formation cannot take place. Lakes and caves, for example, offer some of the highest resolution sedimentary records of human impact and yet are likely to possess, at best, indirect evidence of the development of anthrosols in their catchments.

Even in those terrestrial landscapes upon which anthropogenic soils are able to develop, anthrosols may not represent the stratigraphic base of the Anthropocene. In many terrestrial environments, for example, the earliest impact of human activity is characterised by enhanced erosion. In these circumstances, human disturbance tends to be marked by thick sequences of eroded material. Although anthrosols may develop on these deposits, they are not found at the base of the unit defining the beginning of human impact.

A second difficulty in using soils to define the base of the Anthropocene is that the environmental changes that generate anthrosols do not occur simultaneously worldwide. Although soils may be used for stratigraphic correlation in earlier geological times when they may be regarded as synchronous (see, for example, Demko et al., 2004; Retallack, 2009), the diachroneity that is lost in dating uncertainty in distant times may span a sizeable slice of the epoch when it comes to the Holocene. Thus, although these features may have value locally as markers of the initiation of human environmental impact, they cannot be used as a global golden spike to define the base of the Anthropocene. To be fair, the same difficulty exists with many other signals of human activity, but this is no reason to accept any such indicator as more than a useful local marker of environmental change.

It is unclear from Certini and Scalenghe's (2011) commentary how this problem is to be solved. Conventional stratigraphic procedure requires that the base of each epoch is defined by a golden spike established within a single stratigraphic sequence (Salvador 1994, 29; Remane, 2003, 10; Gradstein et al., 2004b, 23). For the GSSP to be of value, the stratigraphic signal identified at this point must occur elsewhere, with the signal representing the same chronological datum at every site (Gradstein et al., 2004b, 23). But given the diachroneity of the anthrosols claimed to mark the beginning of human impact, this cannot be the case (certainly at the resolution necessary for defining the base of the Anthropocene).

A third requirement of any GSSP is that the part of the reference section within which it is located should display (insofar as it is possible to judge) continuous sedimentation. That is, there should be stratigraphic completeness across the level of the spike (Remane et al., 1996, 79; Gradstein et al., 2004b, 23–24, 27). Yet such a requirement must exclude soils from consideration as golden spikes since soil formation may occur only on exposed land

surfaces. By definition, therefore, the top of the soil must represent a gap in the stratigraphic record.

Fourthly, changes in litho- or biofacies at or near the GSSP should be avoided. Such changes may represent a response to shifts in local environmental conditions that may in turn affect the occurrence of the stratigraphic marker in the sequence. The result may be spurious changes in the marker that reflect site-specific rather than global controls (Remane et al., 1996, 79). Unfortunately, soils will invariably differ in lithology from the bracketing units. As a result, a soil may possess characteristics of human impact that do not exist in the underlying unit, but which reflect differences in lithology rather than evidence for the initiation of human impact. Thus, a soil possessing clear evidence of human modification may form on overbank deposits that represent the product of upstream human-induced erosion but which contain no direct marker of human activity. This criterion for locating golden spikes is a demanding one to meet since, in many terrestrial sequences, human disturbance might be anticipated to produce dramatic changes in litho- and/or biofacies that coincide with the first stratigraphic evidence of human activity.

Fifthly, the ideal GSSP should be located at an horizon amenable to numerical dating or bracketed by datable horizons (Remane et al., 1996, 79; Gradstein et al., 2004b, 27). Whilst soils may be datable, they are composite features that may represent development over long periods of time. Even the highest rates of soil development are little more than $10^{-3}$ m $a^{-1}$, and some modern soils are known to have begun forming more than $10^6$ years ago (Nahon and Lappartient, 1977; Pillans, 1997). Soils are thus chronologically complex and may be poorly suited for use as temporally straightforward golden spikes.

Sixthly, many modern soils are the products of the continuous development of anthrosols that began to form in the early part of the Anthropocene. Since such soils are currently found at the ground surface, they possess little stratigraphic value, particularly in the context of efforts to define the base of an epoch. The classic *Terra Preta* anthrosols of Amazonia, for example, appear to have begun forming in pre-colonial times, yet in places are still intensively cultivated by the local population (see, for example, Eden et al., 1984; Lima et al., 2002). It is difficult to see how features such as these may be employed as markers of the base of the Anthropocene.

Seventhly, following the procedures of the International Commission on Stratigraphy, geochronological units are defined by their lower boundary only (Remane et al., 1996, 77; Remane, 2003, 10). Given this ruling, the golden spike must be placed at the base of the soil. This raises problems of defining the downward extent of the soil (and identifying a worldwide correlation marker at this point) and of human impact (since it may be increasingly difficult with depth to distinguish natural features from ones modified by human activity).

## Discussion

Despite the ostensible attraction of using anthropogenically altered soils to mark the base of the Anthropocene, soils meet few of the criteria required for the establishment of golden spikes. Their preservation potential is poor and they are not found in stratigraphically important environments such as oceans and ice caps. Furthermore, both Remane et al. (1996, 79) and Gradstein et al. (2004b, 27) suggested avoiding coastal and continental settings, exactly the locations in which soil development takes place, when selecting sites for GSSPs. This is presumably because these environments exhibit vertical facies changes, gaps in the sedimentary record and a lack of biostratigraphic markers with a wide geographic range.

Anthrosols do not necessarily provide the first evidence of human impact in stratigraphic sequences. In addition, the initiation of anthrosol development worldwide is markedly diachronous and, although they may provide locally and regionally valuable stratigraphic markers, they cannot provide a golden spike for the start of the Anthropocene. Furthermore, soils are associated with gaps and with changes in lithology in stratigraphic sequences and may not offer either the continuity or the easily interpretable signals required of GSSPs. Soils develop over finite spans of time and do not provide straightforward event markers. Moreover, the development of most anthrosols has continued to the present day. Since they are currently found at the ground surface, they therefore have little stratigraphic value. Partly because of this and partly because of the problem of determining the depth of pedogenesis in a sequence, it is difficult to use soils to define the base of a new epoch.

Even without the challenges of using soils to establish the base of the Anthropocene, it may be that a stratigraphic approach to characterising this period is untenable. Perhaps the most significant problem is that of diachroneity. The earliest evidence of significant human environmental impact may date back tens of thousands of years (see, for example, Turney et al., 2001; Archibald et al., 2012), whilst by the end of the 19th century no part of the Earth's surface can have escaped the effects of human activity (see, for example, Vallelonga et al., 2002, 296; Planchon et al., 2003, 700–701). Although a span of over 40 000 years for the timing of an event is likely to have been of little relevance in earlier geological times, the short timescales of the Holocene and the high resolution of the techniques available for dating this episode make it impossible to hide behind dating uncertainties in defining a single instant for the initiation of human impact. Under these circumstances it is questionable whether efforts to establish a single date for the start of the Anthropocene can have any meaning or value.

Secondly, we cannot ignore the fact that investigations of the Anthropocene do not lie solely (or even mainly) within the remit of the Earth sciences. Reconstructing the environmental history of the late Holocene may involve the employment of data sources that lie beyond conventional stratigraphy. Such sources include tree rings, landscape art and

documentary records. It is arguable that the information obtained from these sources is of greater utility and higher resolution than conventional stratigraphic records in understanding and defining the Anthropocene. There are thus powerful grounds for employing definitions of the Anthropocene that take these alternative sources of environmental information into account. Indeed, there are compelling arguments that any definition of the epoch should lie beyond the constraints of stratigraphy.

## Conclusions

Over the past decade there have been several attempts to establish stratigraphic markers to define the start of the Anthropocene. Most recently, Certini and Scalenghe (2011) have argued that the best markers are anthropogenic soils and that these may be used as a golden spike to identify the base of the Anthropocene in stratigraphic sequences. Unfortunately, soils fail to meet many of the criteria required for the establishment of stratigraphic points:

1. Their preservation potential is poor.
2. Many of the world's stratigraphically most important environments do not experience pedogenesis.
3. In many environments, soils do not necessarily provide the stratigraphically lowest marker of human impact.
4. On a global scale, anthrosol formation is markedly diachronous.
5. Soils are by definition associated with gaps in the stratigraphic record.
6. Soils are associated with changes in litho- or biofacies in stratigraphic sequences, making signals of human impact difficult to interpret.
7. Soils are often compound features that are chronologically complex.
8. Many anthrosols are the product of continuous development from early Anthropocene times to the present, making them of limited value as stratigraphic markers.
9. There are practical and theoretical problems associated with defining the base of anthrosols in order to identify the start of the Anthropocene.

Even without these drawbacks, there are serious difficulties in using stratigraphic methods to define the base of the Anthropocene. In part this is associated with the worldwide diachroneity of human impact and the difficulty of establishing a single chronological datum for the epoch. Although several wide-ranging event markers exist (including bomb-produced isotopes), these fail to coincide with the worldwide initiation of human activity and would appear of little value in defining the initiation of human impact. More significantly, it is arguable that much of the work undertaken on the Anthropocene lies beyond stratigraphy and that a stratigraphic definition of this epoch is unnecessary, constraining and arbitrary.

Soils fail as practical stratigraphic markers of the base of the Anthropocene. More generally, we must ask whether there is any real requirement for a golden spike at the base of the Anthropocene. Any definition of the start of the new epoch must ultimately pass the test of utility; does it have value to those working in the field? We suspect that the global

stratigraphic approach as a whole may eventually prove of limited practical use in studies of human environmental impact.

## Endnote

1. With the exception of a handful of workers who have used alternative terms in an informal sense (see, for example, Crutzen and Steffen, 2003; Ruddiman, 2003), subsequent commentators appear to have followed Crutzen and Stoermer (2000) in assigning the Anthropocene the status of an epoch. Although a re-assessment of the place of the Anthropocene in the stratigraphic hierarchy is out of place here, there would appear to be strong grounds for reviewing the accepted stratigraphic status of the unit.

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