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The chronostratigraphic method is unsuitable for determining the start of the Anthropocene

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Abstract
This paper responds to and supports the earlier 'Three Flaws' paper by William Ruddiman (this journal, 2018). It builds upon his critique of the method used by the Anthropocene Working Group in determining the start date of the Anthropocene. While chronostratigraphy is acknowledged as the best means of establishing a framework for the division of deep time – on geological timescales of millions of years – it is argued that the method is unsuitable for use on archaeological and historical timescales. Close proximity in time between the chronostratigraphic observer and the stratigraphic boundary in question renders the placement of a precisely defined, globally synchronous timeline onto highly time-transgressive evidence inappropriate on these scales of analysis. Application of the method hinders rather than helps understanding of the role of human impact on Earth System change; it leads to a loss of the bigger picture and to relative neglect of the crucial evidence provided by humanly modified ground – the missing strata in most chronostratigraphic accounts of the Anthropocene start. A more ground-up approach is called for. Recognition of humans as geological agents needs to be accompanied by recognition of the distinctive traces of human agency in the ground, which are unprecedented in the stratigraphic records of earlier geological time periods.

Keywords
Anthropocene, chronostratigraphy, GSSP, strata, timescale

I Introduction

Ruddiman (2018) identifies three flaws in the method of the Anthropocene Working Group (AWG) – a subgroup of the International

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Subcommission on Quaternary Stratigraphy – in defining an isochronous chronostratigraphic timeline to signify the onset of the proposed new Anthropocene time division. This paper concurs with Ruddiman's analysis and regards the method as a profound barrier to developing a scientifically useful stratigraphic definition of the Anthropocene. The aim of this paper is to expand on the central point of Ruddiman's critique – that the chronostratigraphic method is unsuitable for determining the start of the proposed new time unit.

It is important to clarify that we are not questioning the validity of chronostratigraphy in the division of time on long-term geological timescales. The accomplishments of that method in providing an essential framework for understanding four and a half billion years of Earth history, as encapsulated in the International Chronostratigraphic Chart (Cohen et al., 2013; Ogg et al., 2016), are widely acknowledged. What is being questioned here is the suitability of the chronostratigraphic method for the division of time on archaeological and historical timescales, which are several orders of magnitude shorter. Our critique applies with particular force to the proposed start of the Anthropocene because of its extreme proximity in time.

The AWG has played a major part in opening up the debate on the Anthropocene as a new interdisciplinary space for exploring human impact on the Earth System and its stratigraphic signal. Collaborative work by members of the group has generated a series of relevant and compelling research papers dealing with highly diachronous evidence at a range of scales – for example, on human bioturbation (Zalasiewicz et al., 2014), the use of plastics as stratigraphic indicators (Zalasiewicz et al., 2016), the scale and diversity of the physical technosphere (Zalasiewicz et al., 2017), underground metropolitan railway systems as a geological proxy of urban growth (Williams et al., in press), and so on. But with regard to its main task of defining the start of the proposed new epoch for geological purposes, the application of the chronostratigraphic method leads to the systematic exclusion of much of that very evidence. The only way the method can deal with time-transgressive signals in strata is through the placement of isochronous timelines upon them, splitting them up into separate time units on either side.

Part of the problem here is that the evidence of strata in the ground is not being given due weight. One might think that a working group set up under the auspices of the International Commission on Stratigraphy, using the chronostratigraphic method, would have strata as its main concern. But let us draw a distinction here between stratigraphy in general (the study of strata in the ground) and chronostratigraphy in particular (the division of time on the basis of stratigraphy). The terms are often used interchangeably in the debate on the Anthropocene, with some slippage of meaning between them. While clearly related, they should not be taken as equivalent to each other. When strata are discussed in this paper, it is the material evidence of the rocks and soils in the ground that is indicated.

II Missing strata

Ruddiman (2018) argues that the chronostratigraphic method, with its requirement for an isochronous basal boundary, ignores the extensive evidence of early changes (Flaw 1) and, furthermore, that it is incapable of acknowledging that evidence (Flaw 2). But his critique hardly goes far enough. For while it is true that the method is unable to get to grips with the immense terraforming of the Earth's surface through the development of agriculture, as he points out, it additionally cannot grasp the associated massive changes resulting from the continuing accumulation of anthropogenic stratal formations (urban occupation deposits, reclaimed land, cultivated soils, landfill, mines, underground metropolitan railway tunnels and shafts, etc.) into the present and trajectories of further growth of these deposits into the future – all of which are part of 'the global effects of human activities' (Crutzen and Stoermer, 2000). In short, it is not just the stratigraphic evidence of agricultural transformations in the past that is overlooked, but the whole time-transgressive body of anthropogenic strata that is still growing and spreading over large parts of the terrestrial surfaces of Earth, sometimes referred to as the archaeosphere (Edgeworth, 2014, 2018), artificial ground (Price et al., 2011), the buried material residue component of the physical technosphere (Zalasiewicz et al., 2017) or the stratigraphic component of the anthroposphere (Ellis and Haff, 2009).

Has the chronostratigraphic method, in the context of this debate, lost its footing in stratigraphy – the study of rocks and soils in the ground? It seems deeply paradoxical that humanly modified ground is not taken as the major part of the stratigraphic basis of a geological epoch defined by human impact. The study of so-called artificial ground does figure in discussions on the stratigraphy of the Anthropocene (Price et al., 2011; Waters et al., 2014), but tends to be accorded a peripheral position, and is not considered to be of central importance with regard to the start. Most evidence advanced for a mid-20th-century onset for the new division, however convincing and compelling it may be, is essentially non-stratigraphic (see the many graphs in Steffen et al., 2004, 2015). Stratigraphic proxies can sometimes be found for indicators specified, but that is not the same as using strata as primary sources of evidence. Strangely, the substantial stratigraphic sequences formed by humans and their domesticated animals and plants over the last 10,000 years or so – and still accumulating at increasing rates today – are regarded as largely irrelevant to the specific task of determining the start of the Anthropocene.

One reason for this is the analytical separation that Earth System Science has recently drawn between the Earth System and the global environment (including the terrestrial environment), with human impacts on the latter seen as largely irrelevant to the former. The logic seems to be that if the start of Anthropocene in the mid-20th century is taken as a globally synchronous shift in the state of the Earth System (Steffen et al., 2016), this can be marked without reference to time-transgressive changes in the global environment (Hamilton, 2015). Many Earth scientists are puzzled by this reasoning.

What could explain, Ruddiman asks, the requirement to shunt extensive evidence of time-transgressive agricultural changes into the 'pre-Anthropocene'? His consternation might well be shared by those who specialize in the study of anthropogenic strata, such as archaeologists, for the time-transgressive changes that Ruddiman refers to did not stop in 1950, and associated archaeological strata did not cease forming at that date. There was no sudden break or moment of transition from a pre-Anthropocene to an Anthropocene state then or at any other juncture – at least as far as evidence in the ground is concerned. The processes of formation of anthropogenic ground kept going and are still continuing today, speeding up and operating at ever-larger scales. We ourselves are active agents in the ongoing accumulation and coalescence of humanly modified ground, though now more through the mediating agency of fossil-fuel-powered earth-moving machines than animal-drawn ploughs and handheld tools alone.

The crux of the matter is that, in seeking to impose a globally isochronous timeline to mark the start of the proposed new interval – as a formal prerequisite in chronostratigraphical classification (Hedberg, 1976) – anything that is not synchronous at a global scale is regarded as peripheral to the central task of fixing the boundary. Since all formations of anthropogenic strata are highly diachronous on human timescales, these are largely taken out of the equation. So too is the evidence for early anthropogenic changes in climate caused by emissions of carbon dioxide, methane and other greenhouse gases from deforestation, land clearing and the production of rice and livestock (Ruddiman, 2003, 2005), correlated with pollen, bones, artefacts and other material evidence from stratified sequences of archaeological deposits (Ellis, 2011; Fuller et al., 2011; Ruddiman et al., 2016). A possible alternative oceanic source has been proposed by critics to attempt to explain the rise of atmospheric carbon dioxide, but the rise in prehistoric methane levels remains otherwise unaccounted for.

Geology and archaeology have always been 'strata-led', in the sense that conceptions of time and past processes are firmly based on observations of evidence in the ground. The empirical base or ground provided by strata is the great strength of those two disciplines. But with regard to the start of the Anthropocene, the traditional 'ground-up' approach has morphed into a more 'top-down' way of proceeding – not so much strata leading and influencing ideas, more a case of ideas imposing their authority on strata, using the material record only as an index (through the use of stratigraphic proxies), for the date of 1950 has already been decided upon for non-stratigraphic reasons. This date is regarded as primary and the strata as secondary. The isochronous timeline that marks the date, being essentially an ideational entity rather than an actual material surface, will be effectively unmappable on the ground. Mappability is a fundamental requirement of boundaries in field archaeology and field geology. If a boundary cannot be mapped, that means it cannot be identified in practical situations. Fieldworkers will be 'left to map a unit conceptually rather than conceptualizing a mappable stratigraphic unit' (Autin and Holbrook, 2012: 61).

The main engagement with actual strata will be in finding a suitable section for the placement of a Global Stratotype Section and Point (GSSP) or 'golden spike' – a basic prerequisite for the definition of a chronostratigraphical unit. Anthropogenic strata have already been largely ruled out for this purpose, in favour of more traditional geological forms of evidence such as speleothems and lake sediments (Waters et al., 2018b). This is partly because of its high diachroneity, and partly because it is often (wrongly) assumed that the existence of anthropogenic strata necessarily implies a sequence break in the form of an unconformable surface, which is not always the case (Edgeworth et al., 2015). Even in the Anthropocene, then, the AWG shows a clear preference for natural archives (Waters et al., 2018a) over anthropogenic archives. No matter what the material evidence of anthropogenic strata might indicate, the intention is to impose the timeline anyway.

The irony is that the strata that are overlooked in the application of a formal stratigraphic boundary, far from being just a passive record, have active effects and impacts on wider ecological systems, being intermeshed with the atmosphere, biosphere, hydrosphere and underlying lithosphere (Brown et al., 2017; Edgeworth, 2018; Ruddiman et al., 2016). As the accumulated (and still accumulating) material residue of past (and present) human actions, these deposits form the buried part of the physical technosphere, the total mass of which has been estimated at roughly 30 trillion tonnes and growing (Zalasiewicz et al., 2017). The rapid transformation of Earth's surface by human societies leaves behind the archaeosphere as its main stratigraphic trace, which will potentially survive into the far future as a 'human event stratum' (Zalasiewicz, 2008). This will include not only the extensive remains of agricultural earthworks such as terraces and cultivated soils, but also (associated and interbedded with these) urban occupation deposits and cut features such as backfilled quarries and other types of humanly modified ground, together with the material culture and novel materials contained therein. Such anthropogenic strata are already all around and underneath us too, raising us up on occasion by several metres – sometimes by tens of metres – providing the foundation level or platform on which universities and conference centres and, indeed, whole cities are built. That build-up of material literally forms the ground on which most Anthropocene discussions take place.

Like Ruddiman, many archaeologists, ecologists, geologists, soil scientists, geographers, geomorphologists and other Earth-oriented investigators are astounded at how such a substantial global trove of stratal evidence can be so underutilized in developing a formal stratigraphic definition of the Anthropocene. As already noted, the main reason given for disregarding the evidence of anthropogenic strata is that it is diachronous, and, therefore, cannot provide the isochronous timeline required for precise boundary definition.

It goes without saying that all stratigraphic evidence is diachronous to some degree. There is, in general, no such thing as a truly globally synchronous event, or isochronous boundary in the ground. The date and time of the detonation of the first Trinity atom bomb test was precisely timed to the nearest second (Zalasiewicz et al., 2015), but the explosive blast, shockwave, plume of radioactive fallout and distribution of radiogenic particles via the atmosphere all unfolded over real time, leaving a stratigraphic signal in soils which is unequally distributed in space and time throughout the world. This is a diachronous signal, not a precisely defined globally synchronous one (though the timeline placed upon it may be isochronous). The same applies to geological evidence of events in the distant past: even the Cretaceous/Tertiary bolide impact and its effects had time duration, albeit relatively short.

But just how diachronous is the evidence provided by anthropogenic strata and the biostratigraphic signals contained therein, compared to the geological evidence upon which most older chronostratigraphic timelines are based? Should diachroneity and synchroneity be regarded as absolute terms or does their meaning shift according to the temporal distance between observer and observed? Are the same criteria applied to diachronous evidence in the present as to diachronous evidence from the distant past?

III A matter of time

In principle, the isochronous boundaries between the time units of chronostratigraphic charts have no time-thickness at all, being simply markers in time. In practice, however, the *sets of evidence in the ground on which those isochronous divisions are based* tend to be thicker in time the further away they are from the scientific observer in the present moment.

A more basic way of putting it is that evidence that appears highly diachronous viewed close up will appear near-synchronous when viewed from millions of years away – and vice versa. In that sense, the terms 'diachronous–synchronous' roughly correspond to the terms 'near–far' – not actually absolute terms with fixed meanings at all, but relative terms that can be applied to the same thing when viewed from variable distances away in time.

Chronostratigraphers of the AWG assume that their methodology should remain the same no matter whether applied to evidence in the recent past or to that of hundreds of millions of years ago. But this assumption is questioned here. If the method is to be usefully applied on timescales similar to those of human history, its focus should be adjusted to take account of close proximity in time. Consider that the average 'age uncertainty' or time-thickness of the 67 GSSPs in the entire Phanerozoic, from the Early Cambrian to the present, is between one and two million years (Figure 1), and that any timeline specified to within half a million years is regarded as high precision (Smith et al., 2014).

On that scale of deep time, the entire archaeological record of agricultural changes over roughly 12,000 years, together with the associated time-transgressive changes in the

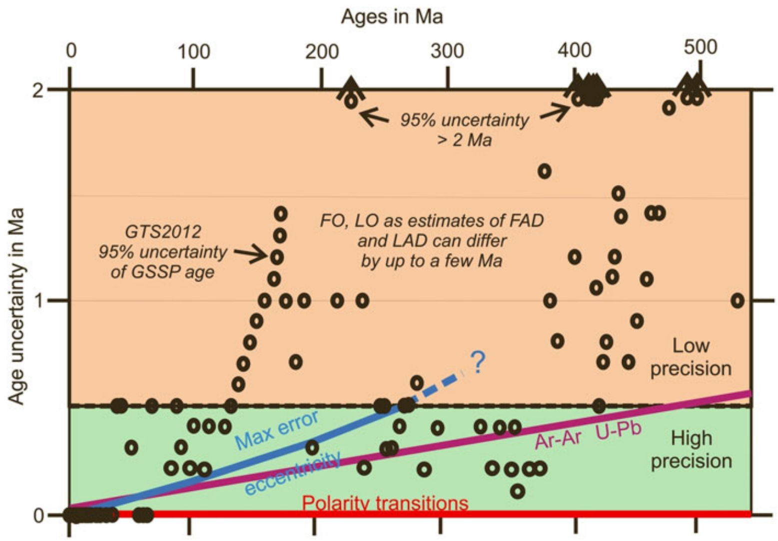

Figure 1. Age uncertainties of GSSPs, mapped into zones of high and low precision (from Smith et al. 2014, courtesy of the Geological Society of London).

biosphere, atmosphere and climate that Ruddiman refers to, constitutes a very high-definition, near-synchronous boundary – indeed, it would be one of the most precise signals on the chart. Yet, as a result of its extreme proximity in time, this evidence is perceived as highly diachronous, and rejected accordingly as unsuitable for the purposes of boundary definition.

This means that different criteria are being applied to different sets of evidence used for boundary definition, according to how near or how far away these are in time from the chronostratigraphic observer in the present. Older boundaries have enough age uncertainty or time-thickness to encompass and make use of diachronous biostratigraphic signals, such as the first and last appearance of fossils in strata, and sometimes the overlapping ranges of several types of fossils. But the closer the boundary is to the present, the greater the time-definition demanded and the more that so-called diachronous evidence (actually near-synchronous on a scale of deep time) is removed from consideration. Such issues have been raised by stratigraphers before, in relation to the end of the Pleistocene (Watson and Wright, 1980), but these problems and paradoxes are compounded many times over in moving further forward in time to date the start of the Anthropocene. The degree of time precision being asked of this latest boundary, within one decade, is over six orders of magnitude (10^6) greater than that of nearly all the boundaries marked by GSSPs in the earlier Phanerozoic. There has been a huge shift in the timescale of chronostratigraphic observations from deep geological time to the much shallower time frames used by archaeologists, historians, ecologists, geographers and other scholars investigating the dynamics of recent times, without any corresponding shift in methodological focus.

Given that most GSSPs are based on biostratigraphic evidence, it is useful to consider the total signal of human-made novel materials to be found in anthropogenic strata, from the first appearance of pottery to the assemblages of manufactured materials in contemporary landfills (concrete, glass, ceramics plastics, metal alloys, paper, Styrofoam, carbon fibre, etc.), over a period of less than 25,000 years. Viewed from 100 million years in the future, the whole sequence would manifest as a near-synchronous biostratigraphic signal of high precision – an 'event' – on which a GSSP and isochronous timeline could be placed without too much difficulty. However, viewed from close-up, and in fact from a situated viewpoint within the very processes of the formation of anthropogenic strata, while the biostratigraphic signal is still being created, it appears as highly diachronous, and is accordingly left out of consideration in the definition and division of chronostratigraphic time.

Chronostratigraphers dealing with the start of the Anthropocene are simply too close in time to the object of study for their conventional practices of isochronous global boundary definition to function as a useful tool in the identification of stratigraphic markers for global time divisions.

The chronostratigraphic chart is often conceptualized as a kind of clock, the face of which is marked by objective units of measurement, like tick marks (reference is made here to informal discussions within the AWG, where the clock analogy is commonly deployed). Thus conceived, the lens it provides is fixed and not easily adjusted. Yet, a more appropriate perspective is to regard it as a kind of telescope, capable of looking back through time from the present, adjusting the focus according to temporal distance between the observer and the observed. The goal of marking time as precisely as possible makes sense when dealing with stratigraphic evidence for global changes hundreds of millions of years distant, with age uncertainties of up to two million years. But the closer the boundary is in time, the less meaningful such precision becomes, as, for example, when the proposed timeline is within a few decades of the present, to be measured in units of less than one year, perhaps even to a single date – for example, July 16, 1945 (Zalasiewicz et al., 2015).

In applying a criterion of maximum precision and fixing the start of the Anthropocene to 1945 or 1950, the larger and more meaningful picture is lost. As Crutzen and Stoermer (2000: 17) initially put it, 'to assign a more specific date to the onset of the "Anthropocene" seems somewhat arbitrary'. In that seminal paper, the authors linked the start of the proposed new epoch with the industrial revolution, though Crutzen subsequently moved his preferred date of onset to the mid-20th century. Plausible cases have since been made for numerous dates of start (e.g. Lewis and Maslin, 2015; Waters et al., 2016), on the basis of many different types of evidence, and proponents have on occasion switched between dates with relative ease, yet none are securely tethered to strata in a convincing way. There is a basic lack of fit between any imposed isochronous timeline and the time-transgressive evidence itself (Edgeworth et al., 2015). In setting an impossible standard of global synchroneity, in the face of manifest high diachroneity of the stratigraphic evidence, chronostratigraphy has embraced *chronos* at the expense of its classic scientific evidence-base rooted in the rock records of this planet. In the context of debate about the start of the Anthropocene, its method becomes all about time and little to do with strata.

Through not adjusting focus when shifting view from distant objects (on the scale of deep time) to near objects (on the scale of human history), or over-adjusting focus in the wrong direction towards yet higher magnification and greater precision, the onset of accelerating trends within a larger set of unfolding diachronous processes is misperceived and mischaracterized as a moment of sudden global transition.

IV Concluding thoughts

Although it is sometimes stated that the placing of a precise Anthropocene boundary will not impede the study of diachronous processes of social-environmental changes at global, regional and local scales, it is hard to imagine anything more damaging, with its inevitable effects of splitting perceptions of long-term stratigraphic sequences and other evidence of continuous and transforming dynamic processes into discrete and instantaneous time divisions, with 'before and after' periods (Bauer and Ellis, 2018).

A formal Anthropocene division defined by a boundary marked in 1950 would require any process or event operating in the year 1949 to be considered as a Holocene process or event, and any operating in the year 1951 to be designated as an Anthropocene one. If such an Anthropocene definition were to be formally approved and published, it can be assumed that journal editors will henceforth treat the Anthropocene in the same way they treat the Holocene and Pleistocene: as formal time units, the boundaries of which have specific dates, not open to redefinition by individual authors. Indeed, the compartmentalization and polarization of thought entailed in boundary placement has already begun, with the setting up of the category of the 'Palaeoanthropocene', defining '*a period of small and regional effects*' (Foley et al., 2013, our italics) preceding the Anthropocene proper. Ruddiman is right to be disconcerted by the introduction of any such pre-Anthropocene category, for it will inevitably be used as a kind of holding enclosure, demoting the significance of time-transgressive evidence of global changes up to 1950, including that of prehistoric climate change.

Research on early anthropogenic global changes in climate, biodiversity, biogeochemistry, geophysics and other changes in the Earth System should be integrated with work investigating more recent times, not corralled into a separate 'pre-Anthropocene' enclosure. To reify the notion of a sudden transition from Palaeoanthropocene to Anthropocene would only further divide researchers and scientific disciplines that ought to be working together. It would encourage scholars and the public to conceptually separate contemporary climate change from its incipient prehistoric origins, making it more difficult to discern long-term trajectories and evaluate accelerating trends (Bauer and Bhan, 2018), collapsing the possibility of multi-scalar analyses of climate impacts (Clark, 1985). It would predispose archaeologists and geologists to perform similar operations on strata, hiving off the post-1950 examples of humanly modified ground from larger stratigraphic sequences of which they are part, constraining ability to see the wider picture of accumulating effects and the spread and transformation of materials through time.

Ruddiman's 'three flaws' analysis rightly resets the focus, enabling a more integrated and long-term understanding of Earth's transformation, as evidenced by strata in the ground alongside other forms of data. To be clear, this is not to deny dramatic recent increases in numerous indicators of anthropogenic effects on the Earth System, such as those of the 'Great Acceleration' (Steffen et al., 2004, 2015). This is about looking at the bigger picture of Earth System change within which the Great Acceleration takes place, resisting the urge to impose global timelines and markers before an adequate understanding of the deeper roots of that change is gained. There is no testable way of knowing at present whether we are dealing with a short-lived episode (perhaps best framed within Event Stratigraphy), a longer-lasting set of changes (that could potentially be framed as a chronostratigraphic time unit of epochal scale) or the start of something larger and more substantial than either of these (of the order of a period or era).

Above all, what is needed is a return to a more empirical 'ground-up' approach, with greater emphasis on the evidence of anthropogenic strata. Basic principles of geological stratigraphy still apply but may need to be modified to take account of configurations of strata that are unprecedented in the pre-human geological record, together with abundant inclusions of trace fossils in the form of artefacts, structures and novel materials that (not being directly subject to the forces of natural selection) are unlike any kind of animal or plant fossil, giving rise to superficially similar but fundamentally different biostratigraphic signatures in the record. Also present in these stratal assemblages are the material remains of plants and animals whose phenotypes have been modified by artificial selection, indicating the emergence of a previously unknown evolutionary force operating alongside and often speeding up or counteracting natural selection processes (Bull and Maron, 2016). There is scope here for collaborations with archaeologists, ecologists and others who have already developed appropriate methods and rationales for dealing with the unique aspects of anthropogenic strata, artificial objects and materials, effects of domestication on species and socio-environmental change on archaeological and historical timescales (Ellis et al., 2016; Harris, 1989, 2014).

Recognition of humans and human social formations as geological agents (together with their 'camp followers' of domesticated animals and plants, not to mention earth-moving machines) must surely be accompanied by recognition of the distinctive marks and traces of that agency in the ground, unparalleled in the stratigraphic records of earlier geological time periods. These missing strata need to be taken into account in any formulation of the start of the Anthropocene.

Where else would one look first to find the stratigraphic basis of the Anthropocene, if not in the deposits and soils themselves?

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