Is the Anthropocene an issue of stratigraphy or pop culture?

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THE ANTHROPOCENE DEBATE

The term *Anthropocene* recently entered into the rhetoric of both the scientific community and the popular environmental movement. Scientific proponents argue that global industrialization drives accelerated Earth-system changes unrivaled in Earth's history. The discussion now filters into geological stratigraphy with proposals to amend formal time stratigraphic nomenclature (Zalasiewicz et al., 2008, 2010). Environmentalists suggest that terms like Anthropocene foster broad social and cultural awareness of human-induced environmental changes. Advocates argue that greater awareness of humanity's role in environmental change encourages sustainable resource utilization.

Formal recognition of a new geologic epoch helps the broader scientific community solidify the idea of humanity as an Earth-system driver. Before the scientific community ventures too far, we wish to offer comment that considers the practicality of the Anthropocene to geological stratigraphy, the science to which it ultimately applies.

SUMMARY OF THE TERM ANTHROPOCENE

Crutzen and Stoermer (2000) suggest that modern technology initiated the transformation of Earth-system behavior and altered environmental processes. They offer the term Anthropocene for the time interval dominated by human activities and indicate that the onset of the human ability to significantly shape Earth's environment became notable with the Industrial Revolution. Steffen et al. (2011) argue that The Great Acceleration after World War II records a dramatic departure in monitored Earth processes from Holocene proxy trends. In contrast, Ruddiman (2005) infers that Holocene-scale anthropogenic greenhouse effects began when humans abandoned hunter-gatherer lifestyles for subsistence settlement, animal domestication, and cultivation agriculture.

The idea that humans interact with nature is not new, and philosophical ideologies about human responsibility permeate historical thinking (Hamilton, 2010; Steffen et al., 2011). *Anthropocene* offers a concept fundamentally different from many precursors. Present human society does not have a symbiotic relationship with nature. Humanity now modifies natural processes, such as biogeochemical cycles, ocean-atmosphere transfers, and flux of surficial sediments (Steffen et al., 2011). Accelerated mass transfer of sediments (Hooke, 2000; Wilkinson, 2005) has particular interest because erosion and sedimentation produce stratigraphic records.

RELEVANCE TO STRATIGRAPHIC PRACTICE

The Anthropocene has taken root in popular culture as a new time term, and scientists embroiled in research and debate on anthropogenic climate change should benefit from formal stratigraphic adoption. However, identification of a basal boundary for the Anthropocene and the suggestion that the concept can be validated with a global stratigraphic marker is at best a bit premature. A distinct stratigraphic marker should have been forming since anthropogenic change began. As practicing stratigraphers, we are taken aback by the claim that scientists currently have sufficient evidence to define a distinctive and lasting imprint of our existence in the geologic record.

Formal stratigraphic practice (ISSC, 1994; NACSN, 2005) uses a codified approach to the development, recognition, and amendment of a timescale relevant to Earth's history. Concepts for stratigraphic units require criteria that allow for the definition, delineation, and correlation of stratiform sequences of Earth materials. Time stratigraphic units represent layers of rock containing lithologic, fossil, mineral, chemical, or geophysical signatures that allow for the recognition and measurement of geologic time.

Because the strata anticipated by the Anthropocene has not yet fully developed and it is only currently possible that a recognizable basal boundary separates it from the Holocene epoch, researchers should find difficulty in using this concept in stratigraphic practice. Stratigraphic boundaries commonly appear as abrupt in the rock record but are often imprecise in time. A boundary as broad as a few thousand years resolves most problems in deep-time stratigraphy but would be of little use to identify a boundary intended to separate events of recent centuries. Definition and delineation of a basal Anthropocene boundary would be sufficient to introduce the term, but the boundary could be potentially arbitrary if it lacks temporal precision. For example, a global marker could be diachronous across millennia if human-accelerated sedimentation were the specific attribute used to mark the basal Anthropocene.

Formal stratigraphic hierarchy (ISSC, 1994; NACSN, 2005) implies that Anthropocene would either hold the rank of epoch if equivalent to the Holocene or age if defined as a subset of the Holocene. Either way, a stratotype that records a continuous, preferably marine, sedimentation record and separates the Anthropocene from underlying units needs to be identified and correlated into the global time stratigraphy. This is a daunting task that may or may not generate significant gains in the

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scientific understanding of anthropogenic Earth processes. Nonetheless, Anthropocene is in fact being used seriously among selected research circles. Workers commonly use Anthropocene informally, and stratigraphic practice does allow for informal nomenclature where suitable to resolve geological problems.

Perhaps the most relevant issue before the International Stratigraphic Commission is the establishment of a scientifically relevant concept that forwards an understanding of the problems we face as humanity interacts with the Earth system. Stratigraphic code clearly states the physical, temporal, spatial, and conceptual requirements for the development of stratigraphic units. On the other hand, the discipline of stratigraphy may also have a reputation to protect. Scientific disciplines maintain their reputation by providing the credible voice a scientific community needs in public debate.

WHAT IS IMPORTANT TO THE GEOSCIENCES?

Anthropocene provides eye-catching jargon, but terminology alone does not produce a useful stratigraphic concept. Social commentators and environmental activists benefit from the term, and it is gaining momentum among the media and writers of popular scientific literature. Scientific use of the term appears to be increasing with public acceptance, although Steffen et al. (2011) argue that the public adopted Anthropocene because of increasing scientific popularity. Perhaps this acceptance is simply because scientists from disciplines other than stratigraphy embrace the concept of Anthropocene while not appreciating the nuances of its application to formal stratigraphic practice. The most important assertion unfolding among these groups is that Anthropocene creates public awareness and formalizes the concept of human-induced environmental change.

Although we acknowledge a distinct allure for the term Anthropocene and recognize merit in the concept, pop culture does not have an interest in the stratigraphic implications of this debate. If there is an underlying desire to make social comment about the implications of human-induced environmental change, Anthropocene clearly is effective. However, being provocative may have greater importance in pop culture than to serious scientific research.

Perhaps one of the more relevant issues we in the scientific community have with terms like Anthropocene is a tendency to market catch phrases that produce questionable labels. Anthropocene has already appeared in the titles of journal papers, presentations at conferences, and proposals for research funding. Modern scientists face pressure to develop and sustain a credibility that fosters research production (Hessels et al., 2009). Could there be a clever end game in mind?

WHAT IS BEST FOR MOTHER EARTH?

We have no issue with people who recognize the ability of modern technology to transform the Earth system as humans manage a global society and economy, nor do we wish to take a stand as to whether the Earth system will eventually be enhanced, catastrophically damaged, or something in between. However, we see value in recognizing the cause and effect of one's actions. The idea that humanity should adopt the role of Earth steward is not new. Global awareness about environmental change is a separate issue from the definition of practical stratigraphic units that solve geological problems.

Modern society struggles with the implications of climate change and now ponders if humans actually alter climate. *Anthropocene* forces us to consider the implications of sending the Earth system into a completely new domain driven by our actions. Does humanity operate on such a grand scale that we drive Earth processes in ways that overshadow tectonic, climatic, and eustatic processes?

Before we amend our stratigraphy and end the Holocene, it would be best to settle the question of where in the stratigraphic record to drive the golden spike that defines when humanity became one of the preeminent forces of nature. Even so, will finding this layer lead to a globally relevant correlation? As stratigraphers, we require criteria to map the Anthropocene with relevant and consistent meaning. Presently, we are left to map a unit conceptually rather than conceptualizing a mappable stratigraphic unit.

If the prescribed conditions are met, then Anthropocene might be a useful time stratigraphic term. In essence, it describes the disruptions driven by human activities. However, elevating terms that may become iconic in pop culture is not in itself sufficient evidence to amend formal stratigraphic practice. Science and society have much to gain from a clear understanding of how humans drive Earth-system processes instead of conducting an esoteric debate about stratigraphic nomenclature. Let the Anthropocene retain its rightful place as a focal point in the culture wars over the recognition and interpretation of environmental process.

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Comment

Response to Autin and Holbrook on "Is the Anthropocene an issue of stratigraphy or pop culture?"

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INTRODUCTION

We thank Whitney Autin and John Holbrook (2012) for their commentary on the Anthropocene concept. This term is under formal consideration by an International Commission on Stratigraphy working group (to which we belong), so critical analysis and comment is welcome and timely. We reply to clarify points raised and to encourage further discussion.

THE SCALE AND SIGNIFICANCE OF THE ANTHROPOCENE

It seems clear to us that human impact is significant on a geological timescale. For instance (1) CO_2 (a key Earth-system driver) has reached levels not seen since Pliocene times; (2) perturbation of the nitrogen cycle may be the greatest since the Proterozoic (Canfield, 2011); (3) the currently elevated species extinction rate, if maintained, will lead to extinction on a "big-five" scale in a few centuries (Barnosky et al. 2011); (4) species invasion levels are unprecedented in Earth's history; and (5) the lithostratigraphic signal of urbanization, agriculture, and resource extraction is substantial and qualitatively unique in Earth's history, particularly in soils and deltaic/coastal regions sensitive to sea level rise.

RELEVANCE TO STRATIGRAPHIC PRACTICE

The Anthropocene needs consideration as both a time unit of geochronology *sensu stricto* (e.g., an Anthropocene Epoch) and a physical stratal record of chronostratigraphy ("time-rock"; i.e., an Anthropocene Series) with component lithostratigraphic, biostratigraphic, chemostratigraphic, and other units. An Anthropocene Series furthermore would comprise all deposits above its boundary, both anthropogenic and natural, including those (volcanic tuffs, desert sands) with no discernable human influence.

However, we do not believe that it is necessary to seek a "boundary stratigraphic marker" that reflects the time "since anthropogenic change began." The issue here is not the presence or absence of human traces in strata. It is whether Earth's stratigraphic record—and the processes that shape it—have changed sufficiently to make a new unit justifiable and useful and, if so, to seek the most effectively traceable boundary horizon for it.

We agree that selecting an effective boundary is not straightforward, with much anthropogenic change diachronous on a scale of centuries to millennia. However, there is potential for boundary selection, whether by Global Standard Stratigraphic Age (GSSA; numerical date) or Global Boundary Stratotype Section and Point (GSSP; "golden spike"). As an example, a putative ca. 1950 boundary would mark widespread expansion of "Artificial Ground" of geological maps (e.g. Price et al. 2011), the worldwide inclusion of measurable radionuclides from atmospheric tests into sediments, and marked shifts in nitrogen isotopes in lacustrine deposits (from global increase in fertilizer use: Holtgrieve et al. 2011).

Few of Earth's other stratigraphic boundaries represent neatly definable, synchronous changes that can be everywhere precisely located. Efforts to recognize an "Anthropocene Series" would prove useful to constraining rates and scales of anthropogenic change to the Earth system.

IS THE ANTHROPOCENE POP CULTURE OR SCIENCE?

The concept has certainly gone beyond the confines of stratigraphic research. But much of the interest has been among the wider scientific community, because *Anthropocene* explicitly compares human perturbation of the Earth system (as observed) with ancient natural perturbations (as preserved via proxy evidence in rock strata), and it considers together and integrates diverse forms of environmental change. This has the novel (in stratigraphy) corollary that the wider scientific community should be considered in the formalization debate (Nature, 2011).

We regard broader popular interest as positive. The Anthropocene has provided a longer-term perspective of humanity's activities and brings stratigraphic principles and practice to a wider audience. Also, the phenomenon of contemporary global change—perhaps unlike the formal determination of past geological time units—potentially concerns everyone.

Autin and Holbrook question our "end game." This is simple. It is to more clearly understand the role of human action in shaping Earth processes on a long-term time scale and, more narrowly, to establish whether there is justification and utility in formalizing the Anthropocene within the Geological Time Scale: these two "end-games" are complementary, in that formal analysis of stratigraphic boundaries, far from being "esoteric," has led to increased understanding of the course and mechanism of fundamental Earth processes in deep time.

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We hope this helps answer the queries of Austin and Holbrook. We emphasize that the Anthropocene, as articulated by Crutzen (2002), is a new concept and its study, both in formal stratigraphy and more widely, is work in progress. Its potential utility and significance make sustained, thorough study worthwhile, and we welcome further discussion.

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Reply

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We thank Jan Zalasiewicz and his colleagues for their thoughtful review and critique of our comment on the stratigraphic relevance of the term *Anthropocene*. We agree that broad and open discussion is useful; however, we wish to clearly iterate that we are not taking a position as flag bearers for the anti-Anthropocene side of the debate. We simply wish to offer our concerns about the formal adoption of the Anthropocene into stratigraphic practice and its growing interplay with the environmental movement at large.

Amendment of stratigraphic code requires a formal process, and proposals that do not ultimately provide useful field application are unlikely to gain traction within the scientific community. Regardless of whether Zalasiewicz et al. feel a need "to seek a boundary stratigraphic marker." stratigraphic code is explicit in the requirement to establish boundary stratotypes with widespread, preferably global, correlation significance. Recognition of a boundary stratotype is a practical requirement that must also prove necessary and useful to the resolution of field stratigraphic problems. Neglecting to develop stratotypes or deferring the definition of boundary criteria to future generations should inhibit the acceptance of Anthropocene as a practical stratigraphic concept. If developing a consistently recognizable stratotype is indeed such a challenge, then the stratigraphic utility of the concept is in question from the onset.

Establishing rock and time stratigraphies are partially separate exercises because they depend on different criteria. Lithostratigraphy depends on physical changes in sediment character that define boundaries mapped with consistent and objective criteria. Anthropogenic markers are used in Quaternary stratigraphy, but no single marker defines a mappable shift to human environmental dominance. Instead, currently recognized markers define a temporally and spatially diverse sequence of human events recorded as a complex and variable stratigraphy. Furthermore, such markers are not consistently used in all settings, but they are informally chosen to suit local stratigraphic practice. We can think of few, if any, markers that are globally consistent and therefore suitable candidates for a stratotype. In contrast, chronostratigraphy defines the time that a stratigraphic marker formed with mappable features that conform to identified time lines. Modern geochemical and radiometric techniques can establish time lines in strata of historic age; however, which precise temporal datum reflects the onset of Anthropocene is still an open question. Presently, the selection of markers to identify the base of the Anthropocene seems arbitrary and may be of little stratigraphic use, particularly since the impact of humans appears acutely time transgressive across the Holocene.

The debate about stratigraphic relevance is primarily deductive in that global change theory suggests there must be a physical, chemical, or biological signal of human alteration consistent with the projected exponential rate of environmental change. Therefore, the data we collect should identify a master stratigraphic marker. This reasoning is contrasted with inductive analysis where one finds a signal and seeks to explain its occurrence. Proposals for Anthropocene time- or rock-stratigraphic units did not arise because we found a practical, mappable, and useful stratigraphic boundary that marks a discrete onset of modern human influence to the Earth system. In contrast, Anthropocene appears to interject a conceptual idea onto the stratigraphic record. In the present day of deductive dominance, is the simple scientific reasoning that suggests observations trump theory now considered outdated?

In summary, the scientific community will attain greater benefit by recognizing human-induced environmental processes instead of chasing nomenclature that did not arise independently of ideology. With regard to "the end game," we suggest that recognizing the causes of environmental change by either human or other causal mechanisms is a critical research topic to which geoscientists of all specialties can contribute. However, our discipline can best contribute to society by maintaining a focus on using our resources to solve problems that benefit the sustainability of the Earth system.

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