COMMENTS AND REPLIES

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Reply

Zalasiewicz et al. Comment

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We thank Jan Zalasiewicz and his 25 co-authors for their considered response. We are in complete agreement with the following two major statements:

"All chronostratigraphic units are defined by their base and characterized by their content;"

and

"There are clearly societal and political ramifications to the Anthropocene, and to any decision made regarding it, as remains the case for global warming science. That does not disqualify it from scientific analysis, nor from potential geologic formalization. Rather it enhances the case for the rigorous scrutiny it is undergoing."

However, we categorically disagree with this statement:

> The description of the International Chronostratigraphic Chart by Finney and Edwards misses an important element of the formulation of chronostratigraphic units. These differ one from another, and justify distinct names, not simply because of the lowest occurrence of a fossil species or chemical marker, but by more fundamental changes, for instance to biotic assemblages, ocean/atmospheric chemistry and sediment production, which control stratal character. We note that the periods quoted (*viz.* Ordovician, Devonian, Carboniferous, and Permian) represent major Earth System changes that are reflected in stratigraphic and paleontologic character, even if the lower boundaries are selected using the best correlatory signals.

The traditional units of the International Chronostratigraphic Chart (http://www.stratigraphy.org/index.php/ics-chart-timescale) were based on local stratigraphic successions that accumulated in sedimentary basins that were controlled in large part by regional tectonics, climatic and depositional settings, and sea level. Later they were extended to stratigraphic successions in other areas primarily through biostratigraphic correlation. Throughout the entire stratigraphic column, coeval stratigraphic successions and their biostratigraphic attributes vary greatly among paleoenvironmental and paleogeographic settings, and this variation resulted in a proliferation of regional chronostratigraphic classifications as demonstrated by the correlation chart for the Ordovician System (http://www.stratigraphy.org/upload/OrdChartHigh.jpg). To address the resulting complexity, the International Commission on Stratigraphy was founded to establish a single hierarchical set of global chronostratigraphic units with their lower boundaries defined by Global Standard Stratigraphic Sections and Points (GSSPs). Had the traditional units been established from regions other than the classic areas of northwest Europe, the Chart would consist of a very different set of units in both stratigraphic extent and lithologic character and with completely different names.

Global events have indeed left distinctive stratigraphic records (e.g., Cretaceous-Paleogene impact/extinction; end-Permian mass extinction; Hirnantian glaciation; Paleocene-Eocene thermal maximum), but these are few in number relative to the 102 stage boundaries of the Phanerozic Eonothem, some of which also coincide with and formally define boundaries of series, systems, and erathems. Furthermore, extensive stratigraphic records of many major events extend from well within one system to well into the next (e.g., the Cambrian–Middle Ordovician Sauk transgression that flooded Laurentia; the spread of forests and the Acadian orogeny through the Devonian, the effects of which continued well into the Carboniferous). The global effects of all major Earth System events, such as the Alpine orogeny, extend across system/period boundaries. In a few instances, the geologic changes marked by stage boundaries are far greater than those that occur at series and system boundaries (e.g., the Frasnian-Famennian). In fact, the nature and magnitude of stratigraphic signals used to place unit boundaries (biostratigraphic, chemostratigraphic, and magnetostratigraphic sequence stratigraphic) typically also occur *within* chronostratigraphic units.

In sum, a boundary between formal chronostratigraphic units may be placed at a horizon of fundamental change or it may be placed at a horizon without fundamental change. Conversely, a fundamental change in "biotic assemblages, ocean/atmospheric chemistry and sediment production, which control stratal character" may occur at or near a formal chronostratigraphic boundary or it may not. We must emphasize also that climate and other components of the Earth System may exhibit transitions, but the International Chronostratigraphic Chart does not. It has boundaries. If the Anthropocene is to become a formal chronostratigraphic unit, a single unambiguous lower boundary in a key stratigraphic section must be proposed and accepted.

The unit and its boundary must be documented with stratigraphic logs from a range of depositional and geographic settings, and their correlation potential evaluated and shown to be reliable. This is the rigorous, objective, and consistent process by which all units of the International Chronostratigraphic Chart are defined. Furthermore, given that historical geologic and human-induced events and the material bodies and signals they produce are directly observed and dated with the human calendar (e.g., Poland et al., 2016) and are already shown on geologic, topographic, and geographic maps with very useful specific names and symbols, the usefulness of the Anthropocene as a *chronostratigraphic* unit must be demonstrated if it is to be considered by the International Commission on Stratigraphy.

We agree with Zalasiewicz et al. that human impact has resulted in widespread, distinctive material bodies that may enter the rock

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record. However, still lacking is a formal proposal containing the requisite documentation in the form of stratigraphic logs through the proposed unit and well down into the underlying Holocene, stratigraphic characterization of the unit, a consideration of the potential lower boundary horizons, the differences in stratigraphic content above and below the potential boundaries, and the correlation of the favored stratotype unit and its lower boundary into stratal successions in a range of depositional environments and geographic areas. This applies to the radionuclides, which have been proposed repeatedly for defining the boundary, as well as the other particulate and chemical signatures cited as signals of human impact. Also presently lacking is a demonstration of the geologic *utility* of an Anthropocene chronostratigraphic unit. When a formal proposal is complete, the voting members of the Quaternary Subcommission and then the executive officers and chairs of the 16 subcommissions of the International Commission on Stratigraphy will evaluate it critically, as they do all formally proposed chronostratigraphic units.

As has been noted recently (Edwards, 2015; Autin, 2016), the term "Anthropocene" has taken on a variety of meanings for different groups or disciplines. Formalization by the International Commission on Stratigraphy could remove much of the ambiguity. Alternatively, a formalized definition will likely not be consistent with the concept of the term as used by many, and would likely leave lower (earlier), widespread stratal records of human impact in the Holocene, including almost all of those cited in the Comment as being distinctive of the Anthropocene. If not formally defined and ratified as a *chronostratigraphic* unit, the term Anthropocene could convey a consist meaning (human impact on the Earth system) to all users. It is in the best interest of geology that confusion is avoided.

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