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Anthropocene

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The world today is undergoing rapid environmental change, driven by human population growth and economic development. This change encompasses such diverse phenomena as the clearing of rainforests for agriculture, the eutrophication of lakes and shallow seas by fertilizer run-off, depletion of fish stocks, acid rain, and global warming. These changes are cause for concern—or alarm—among some, and are regrettable if unavoidable side effects of economic growth for others.

How significant are these changes in total? How might they evolve, and what might their ultimate consequences be? One way of studying these changes is to consider them as the latest phase of the many environmental changes that have affected the Earth since its origin, a little over four and a half billion years ago. Humans may be considered as geological agents, and anthropogenic environmental change may be compared with events in Earth's deep history.

Such analysis dates, perhaps surprisingly, from the earliest days of organized geological study. Working before the French Revolution, the Comte de Buffon wrote arguably the first evidence-based geological history of the world—*Les Époques de la Nature*, published in 1788 (Roger 1962): his seventh and final epoch denoted the time during which humans dominated and warmed (beneficially, Buffon thought) the Earth. (While Buffon's theories of racial environmentalism have largely been dismissed, his thoughts on geological time and process remain important to contemporary discussions of the Anthropocene.) Later, works by the likes of

George Perkins Marsh (1864) and Antonio Stoppani (1873—he proposed the term "Anthropozoic") noted the growing impact of humans on Earth, with the likes of Vladimir Vernadsky (1945) and Robert Sherlock (1922) then developing various aspects of this concept.

Throughout the twentieth century, most geologists (e.g., Berry 1925) dismissed human impact as insignificant when set against the broad canvas of Earth history. This was the case partly because of the time scale. The ten-thousand-year span of human civilization is barely significant on the scale of geological time, while the phase of industrialization is far shorter still. Furthermore, the great natural forces of the Earth—mountain building, volcanic outbursts, meteorite impacts, and so on—were regarded as of far greater long-term significance than the brief human alteration of an ephemeral landscape.

This changed when Paul Crutzen (Crutzen & Stoermer 2000; Crutzen 2002) proposed that we were now living in the Anthropocene, because of the scale of the human-driven chemical, physical, and biological changes to the Earth's atmosphere, land surface, and oceans. The Anthropocene (an "Anthrocene" had also been proposed a little earlier by Revkin 1992) caught on, and began to be used almost immediately by a wide range of scientists and made an impact among the general public.

Why the change in opinion? First, it was becoming clear that while human impacts may be geologically brief, they are not trivial. Some "invisible" effects—such as increases in carbon dioxide levels in the atmosphere—can lead to profound physiographic effects by their influence upon global temperature and therefore (through the melting of ice) on sea level. Second, the term was found useful as a means of integrating and conveying the different types of global change. Third—and particularly as regards public impact—the word itself is evocative, overtly placing humans upon the same geological narrative (one of almost infinite duration!) that the dinosaurs once occupied.

Where is the concept at present? As an informal term, it now seems firmly established in the sciences—and in the arts too. It has been the focus of studies published by the Royal Society (Williams et al. 2011), of a major initiative of the International Geosphere-Biosphere Programme (IGBP: http://www.igbp.net/), and a major modern art exhibition at the Haus der Kulturen der Welt in Berlin in 2013-4. The use of this term to denote the current time interval seems set to continue, and probably spread.

Given this widespread use in practice, the Anthropocene is being formally considered as a possible addition to the Geological Time Scale by an Anthropocene Working Group of the Internal Commission on Stratigraphy (http://www.quaternary.stratigraphy.org.uk/workinggroups/anthropocene/). It may, therefore, join "Jurassic," "Pleistocene," and other terms that underpin the science of geology (Zalasiewicz et al. 2010). This process will involve much detailed analysis over the coming years, and formalization is not assured. The term has to be shown to be not only technically valid but also of practical value (rather than a hindrance) to working Earth scientists.

One benefit of formalization would be precise definition, for currently there is no accepted date for the beginning of the Anthropocene. It is mostly used in Paul Crutzen's (2002) meaning, as dating from the Industrial Revolution, at around 1800 CE. However, in geology, a geological time boundary must be both synchronous (by definition) and also effectively recognizable in strata. In the case of the Anthropocene, these strata include artificial deposits produced as a consequence of urban development and mineral extraction (Price et al. in Williams et al. 2011; Ford et al. in Waters et al. 2014), damming of rivers, deforestation, and coastal reclamation (Syvitski and Kettner in Williams et al. 2011) and also deposits lacking discernable human influence—those of remote desert dunes, for instance. The “human-made strata” locally date from before the Industrial Revolution, and in general are strongly diachronous (i.e., formed at different times in different places), reflecting the spread of human civilizations around the globe over several millennia.

One potential boundary that is both widely detectable in sediments and approximately synchronous is the spread of radionuclides from atmospheric nuclear weapons tests (Zalasiewicz et al. 2015; Waters et al. 2015) and of fixed nitrogen from fertilizer manufacture (Holtgrieve et al. 2011), both of which date from ca 1950 CE. This date broadly coincides with “The Great Acceleration” (see Steffen et al. in Williams et al. 2011), during which the use of natural resources and the emission of pollutants increased rapidly. The pros and cons of various boundary candidates need to be considered prior to any decision on formalization.

Formally, there is the question, too, of the hierarchical level of the Anthropocene, for the geological time scale consists of smaller units nested within larger ones. Thus, currently (formally), we are living within the Holocene Epoch, which is a part of the Quaternary Period (which began 2.58 million years ago, when the Earth became glaciated at both poles), which lies within the Cenozoic Era (which began at the mass extinction event sixty-six million years ago, when the dinosaurs and much else became extinct), which in turn is part of the Phanerozoic Eon (which began over a half-billion years ago, with the sudden and widespread appearance of complex animal behavior in the fossil record, represented by the burrowing traces of those organisms).

Currently, the Anthropocene is being considered as an epoch (Zalasiewicz et al. 2015). If that is accepted, then the Holocene has formally terminated (though the Quaternary, Cenozoic, and Phanerozoic would continue). There are other possibilities, such as a period on one hand and an age (a subdivision of an epoch) on another. The hierarchical level ultimately chosen should, at least in part, reflect the scale of environmental change (which will in turn determine the distinctiveness of future geological strata). How does the Anthropocene currently seem to be measuring up?

The answer is not straightforward, as the component phenomena of the Anthropocene are evolving rapidly and, for the most part, are in their early stages. Future (imperfectly predictable) trends will develop over many millennia at least.

Geological changes so far include some that are entirely novel in Earth history. Most distinctive are the "urban strata," which may be thought to approximate to (eminently fossilizable) gigantic trace fossil systems currently spreading across and beneath terrestrial surfaces (Zalasiewicz et al. 2014; Zalasiewicz, Waters, and Williams 2014). Of chemical changes to the environment, the human-driven influx of carbon from rock strata into the atmosphere is (as yet) smaller in scale than geologically ancient, natural outbursts such as that of the Paleocene-Eocene Thermal Maximum, some fifty-five million years ago; but, it has taken place more rapidly—over a couple of centuries rather than over several millennia (Ridgwell and Schmidt 2010). That ancient event led to warming of some 5–8° C globally (a process that is now in its early stages) and significant sea level rise (something that, currently, has barely begun).

Ultimately, the most important changes are those to the biosphere, the sum of which are now colossal (Williams et al. 2015). These changes are complex, having begun on the land before affecting the sea. They include species extinctions, though the scale does not yet approach the "big five" mass extinctions of the past 500 million years. But, with many species now critically endangered, "business-as-usual" will probably see a comparable mass extinction within a few centuries (Barnosky et al. 2011). A related biological change is already on a scale without precedent in Earth history: the species translocated across the globe by humans, consciously or unwittingly. These mass species invasions have led to the proposal of a "Homogenocene" (Samways 1999). Any such biological change has permanent effects, as it determines the course of future evolution. In this sense, the course of Earth history has already been reset.

The Anthropocene is hence multifactorial (and the factors naturally interrelate, for instance as climate warming drives further biological change), complex, evolving, and in its early stages. What does it mean more widely for society? First, it provides an integrated overview of climate change, related to such concepts as planetary boundaries—the limits that should not be exceeded to ensure a functional Earth system. It may be criticized for undermining efforts at conservation (Caro et al. 2011), or invoked to accept (and take responsibility for) human planetary domination (Ellis, Antill, and Kreft 2012). Even its formalization may have significance beyond geological nomenclature, being significant to international environmental law (Vidas, in Williams et al. 2011). Its evolution, as a concept and as observed geological reality, will encompass the future of this planet and of its inhabitants.

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