

THE ANTHROPOCENE: HAVE WE CREATED A NEW GEOLOGICAL TIME INTERVAL?

The term “Anthropocene” was coined by Paul Crutzen 16 years ago to mark the present as distinct from previous geological time. The term has since flourished in both scientific and popular publications, but without definition it has developed many meanings. In 2009 the Anthropocene Working Group (AWG) was established to advise the Subcommission on Quaternary Stratigraphy (SQS), the body responsible for classification of the past 2.6 million years of Earth history, on the term’s merit and potentially to propose a definition based upon the geological evidence. The quest to subdivide geological time into sensible and strictly defined units, of the Geological Time Scale <http://www.stratigraphy.org/index.php/ics-chart-timescale>, is one of the cornerstones of the geological sciences and decisions to incorporate new units are not taken lightly.

Why is the Anthropocene concept raising so much interest?

Until recently the perception was that natural processes occurred on such vast scales that human influence, by comparison, was negligible. But increasingly, scientists monitoring and recording historical environmental change have emphasised the considerable scale and reach of human perturbation of natural systems. Most geological boundaries are marked by slow progressive changes and the Anthropocene is spectacular in the extent and speed of change, over decades rather than millennia.

The geosciences are pertinent to understanding modern processes, providing the tool to witness the scale and speed of current environmental change and to compare with non-anthropogenic events of the geological past. But the AWG comprises a broader membership, recognising the greater diversity of signals required to characterise the Anthropocene compared with “traditional” geological successions. The AWG deciphers vast and diverse environmental data sets collected by disparate research groups into a format that summarises the interlinked changes to our planet.

In the recent publication in *Science*, many, though not all, AWG members proposed that the recent scale of environmental changes are as great, if not greater, than those deduced at the start of the Holocene Epoch, which started 11,700 years ago during the transition from the last ice-age to our current warmer state. Thus, it is argued, the Anthropocene should have the same hierarchical level, and if approved, would mean the Holocene Epoch has finished and the Anthropocene has started, and for the first time a single species has knowingly been the agent of such transition. Humanity has excelled at geoengineering the planet into one that sustains 7 billion people, living longer lives than at any point in human existence. But the signals described in the *Science* article express evidence that our ever-increasing consumption is also changing fundamental aspects of the Earth’s system away from stability.

In the distant future what evidence will humanity have left behind that will be recognisable as the Anthropocene?

Many of the environmental signals considered by the AWG are novel to the Anthropocene, and their dramatically increased abundance since the 1950s may be seen in production statistics. But it is

necessary that they also have a physical expression in rocks/sediment/ice that will leave a permanent record.

Aluminium, a rare naturally occurring native metal, has replaced tin in the production of cans, foil and lighter vehicles. Enough has been produced in 60 years to cover the contiguous states of USA and part of Canada in a layer of foil. Concrete has been around for 2000 years, but as the modern building material of choice it represents a new form of geological rock that locally accumulates much faster than natural sediments. Total production to date equates to ~1 kg of concrete per square metre of the planet. In reality concrete is largely a terrestrial phenomenon, though one increasingly injected to form subterranean structures which will persist long after erosion removes the upper layers of our terrestrial environment. Enough plastic has been produced since the 1950s to wrap the entire planet in a layer of cling film. Plastic extends beyond our terrestrial realm to pollute the oceans, providing a potential global signature. Given plastic's novelty, its longevity is poorly known, potentially decades to centuries, but may be much longer in deep oceans and when buried in strata. When plastic ultimately decays back to source hydrocarbons it will leave a persistent geochemical signature and fossil trace. Such technofossils are comparable to traditional biotic fossils in that they will lack their original organic composition, but will leave a mineralised impression fixed in rock.

Some novel materials are unwanted by-products of technological development. Black carbon and spheroidal fuel ash, both resulting from fossil fuel combustion, show initial regional elevated concentrations during the Industrial Revolution, with dramatic global upturns in abundance in 1970 and 1950, respectively. Concentrations have peaked and decommissioning thermal power stations and investing in renewable energy sources should continue to cause decreased signals. Similarly, atmospheric testing of nuclear devices generated fallout from 1945 to 1980, with rapid decline after the Partial Nuclear Test Ban Treaty of 1963, though locally augmented by accidental discharges from power stations, reprocessing plants, and satellite re-entries. Most anthropogenic radionuclides present in the environment today are locked in soils, sediments or glacial ice, but radionuclides are still slowly settling through the water column within the deepest oceans. Large components of the fallout have short half-lives, e.g. $^{137}\text{caesium}$ and $^{90}\text{strontium}$, and much has already decayed to stable daughter products. Longer duration signals from $^{239}\text{plutonium}$ will be detectable by modern mass spectrographic techniques for about 100,000 years into the future; following decay it will leave a layer enriched in $^{235}\text{uranium}$ and ultimately stable $^{207}\text{lead}$, recognisable as a permanent signature.

Other signals occur naturally, but currently exist outside the range experienced during pre-industrial Holocene norms. Climate change, at least the measurement of increased temperatures, increased storminess and rising sea-levels, can be seen indirectly through proxies such as oxygen isotope ratios that change with ice volume/temperature, or sediments that record flooding of coastal zones during rising sea-level. Atmospheric carbon dioxide and methane concentrations are at their highest for the 800,000 years of glacial ice record. Rates of increase in these gases since the mid-20th century are phenomenal, CO₂ increasing 120 times faster than during the start of the Holocene. Nitrates are recorded in remote lake deposits and glacial ice and much of the upturn in concentrations, now higher than recorded in the past 100,000 years, relates to generation of artificial fertilizers following introduction of the Haber-Bosch process in the early 20th century and nitrogen oxides from combustion of fossil fuels.

Animals and plants will become the fossils of the future and could be used the way geologists have used fossils to distinguish strata into distinct time units throughout the last half billion years of geological history. There is evidence for modern biodiversity loss with elevated extinction rates, between 10–1000 times above background rates. But, perhaps it is the increased levels of species invasions which mark the Anthropocene as novel. Such continental transfer of species, previously the result of continental collisions, is now evident worldwide as homogenisation of the domesticated vertebrates or crop cultivars that provide our food, or through accidental transfer in response to our global network of trade.

Would future geologists understand that humans were the cause of these changes? When it comes to classification of the time interval, it is the scale of the signal, and not the cause, which ultimately marks the Anthropocene as distinct from the Holocene.

When did the Anthropocene commence and when will it finish?

There is considerable debate as to whether there should be a distinction between the Holocene and Anthropocene epochs. The start of the Holocene represented a response to natural climate change, part of the cyclical variation in the orientation of the Earth's orbit around the sun. Modern humans have existed for about 200,000 years, but the amelioration of climate during the Holocene has coincided with, probably fostered, initiation of many human social developments that characterise our modern civilization, e.g. living in settlements, introducing agriculture and domesticating livestock and causing deforestation. The global transfer of these undoubtedly important developments across land was on millennial scales. By contrast, the Anthropocene is characterised by humanity's influence being truly global, not just on the land we inhabit, but in the oceans, atmosphere and glacial ice, and at the same time the changes are very much more rapid – on annual to decadal scales.

The mid-20th century 'Great Acceleration' of population growth (our numbers growing by 4.5 billion in a little over 60 years) has caused greater consumption of resources (minerals, hydrocarbons, food, water, land etc.). This, in turn, has increased demands placed upon the environment that are expressed in the numerous physical signals described above. Industrialization and technological advances, such as development of plastics, can as a consequence of globalisation of trade allow artefacts to span the globe only a few decades post-invention. Increased cultivation and road construction, particularly in the tropics, has greatly increased erosion and mass transport of sediment into rivers, but at the same time construction of large dams, at a rate greater than 1 per day over the past 60 years, seriously inhibits the amount of sediment that finally reaches the oceans. We have generated a new geological force: the extraction and vast transfer of sediments/minerals about the planet to our cities to support construction and consumption. Mineral extraction alone is about three times the magnitude of the "natural" mass transfer of sediments by rivers or glaciers, which emphasises how greatly the Anthropocene world differs from all previous epochs.

Epochs do not have set durations, so it is not possible to predict when the Anthropocene will end. The role of the AWG is not to predict the future, but to indicate the nature of the geological record we are currently leaving that will be evident to future geologists. However, there are possible scenarios that can be envisioned. A world free of significant human perturbation may expect in tens of thousands of years to return to a new ice age that may significantly inhibit our continued global influence. But, our geoengineering of the planet may defer that expected glaciation for at least

100,000 years – or potentially even cancel it. Furthermore, it is argued that Earth is heading towards a mass extinction event, where greater than 75% of species are lost. This has happened only five times over the past 450 million years and to happen again would represent a permanent change to our planet. But some of the signatures we discuss are evident as spikes, and the peak signal has already passed, showing that it is within our capability as a species to reverse global trends for other pollutants. Many of the biological changes, though are irreversible, and in this respect the course of Earth's history has been changed.

How will the research progress?

Producing a formal definition is a complex and lengthy process, and can fall at any of a number of stages. The AWG would need to reach consensus agreement on a formal definition proposed in a suitable peer-reviewed publication. The current *Science* paper is only part of the evidence-base, but is in no way that formal proposal. The SQS must vote on any proposal, and if positive it would then go to the International Commission on Stratigraphy to vote on. Again, if positive, the issue goes to the International Union of Geological Sciences who either ratify the proposal, send it back for more work, or reject it altogether.

A critical next stage is to investigate the potential environments that might be most suited to locate a Global Boundary Stratotype Section and Point (GSSP), e.g. oceans, lakes, glacial ice, even landfill sites. Then, it will be necessary to carry out a broad spectrum analysis of those signatures described above in either existing or newly acquired borehole core. All of those signals are part of the mix that will guide the location of the base of Anthropocene strata, but ultimately the most robust, widespread, clear and durable signal will be selected, upon which the definition will be based. The AWG seeks to engage in open debate with, and gain input from, the wider scientific community prior to making recommendations to the SQS. The wider research community will be a critical component in providing the evidence base for such a proposal and we welcome your contribution.

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