Enter the Anthropocene - an Epoch of time characterised by humans

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Introduction

In the first years of the 21st century Earth was being influenced by forces greater than our own and yet as vulnerable. With infinite complacency men and women went to and fro over this globe about their affairs, serene in their assurance of their empire over matter. And yet, across the vastness of time Earth viewed the actions of people with increasing despair. And slowly, but surely, she drew her plans against us…..

We have borrowed these words, with some poetic licence, from H.G. Wells' late Victorian science fiction spectacular *The War of Worlds*. Wells' carefully crafted opening salvo to his novel contains words prescient in the early 21st century as we face the prospect of rapid change to our climate, and warns us about complacency in the belief of our dominion over nature. Already in the late 19th century many scientists were commenting on the extent of human influence on planet Earth. The Italian geologist Antonio Stoppani (1873) was perhaps the first to moot these ideas. Later, as the 19th century drew to a close the Swede Arrhenius and the American Chamberlain worked out the relationship between the amount of CO_2 in the atmosphere and global warming. Arrhenius suggested that future generations of humans would need to raise surface temperatures to provide new areas of agricultural land and thus feed a growing population. But he could not have conceived of the massive rate of human population increase in the 20th century. In 2002 the Nobel Prize winning scientist Paul Crutzen resurrected the concept of the Anthropocene to denote the ever increasing influence of humans on Earth. The word has now entered the scientific literature as a vivid expression of the degree of environmental change on planet Earth caused by humans (Zalasiewicz et al. 2008 and references therein).

For the Anthropocene to become useful though, it needs some quantification. How might an Anthropocene Epoch be unique relative to the Holocene or the Pleistocene epochs that preceded it? What criteria could we use to quantify when the Anthropocene began, and how might future generations of geologists recognise its signal in the rock record? More importantly though, does the term Anthropocene help us to understand the influence of humans on our world and how that affects the environment of the near future?

How unique is the Anthropocene?

The use of tools was once thought to distinguish humans from all other animals, and indeed the earliest people who lived two million years ago in Africa are called *Homo habilis*, the 'handy man'. But the origins of human technology are deeper, revealed in the actions of our primate cousins fishing for termites with a twig, or breaking the shells of molluscs or nuts to find the original fast food. For a long time then, in fact for more than a million years, people have been modifying planet Earth. For much of that human story technology was little more than muscle and sinew, supplemented later by fire. Traces of humans in the Pleistocene rock record are therefore rare, and stay rare until the Holocene.

The influence of humans is felt more strongly towards the end of the Pleistocene Epoch with the demise of the so called 'megafauna' that included the sabre toothed cats in North America or the woolly mammoths of Siberia. On many continents the disappearance of the megafauna appears to coincide with the arrival of modern humans. Like many events in the geological record this extinction is diachronous – that is, it didn't all happen in an instance. Thus, the megafauna disappeared in Australia 50,000 years ago, but in the Americas 13,000 years ago. Yet, the megafauna are still living in parts of Africa and south Asia, albeit under threat nearly everywhere it persists. From the beginning of the Holocene, about 11,000 years ago, there is more widespread evidence for human activities, with the rise of agriculture beginning first in the 'Fertile Crescent' of the Middle East and gradually extending to northern Europe by 6000 years ago (Ruddiman 2003). This change of cultivation leaves a clear fossil record in the pollen preserved in sedimentary successions through this interval. And, the clearance of forests, associated with the rise of agriculture may have begun to elevate CO_2 levels in the atmosphere long before the Industrial Revolution (Ruddiman 2003).

Following the Neolithic revolution of agriculture, humans began to live in villages and towns, and by the third millennium BC the cities of ancient Mesopotamia, the Nile Valley, and the Indus Basin of Pakistan were well established and culturally distinctive. Still later, urban cultures spread across the tropical and temperate zone everywhere, with those in Europe, central and South America, and China being diverse and advanced by the first Millenium BC. This rate of urbanisation has accelerated through time, with the first million cities possibly appearing in late medieval times, such as Angkor in Cambodia. By the 19th century London and Paris had clearly reached this zenith, and now there are many cities with between 10 and 20 million inhabitants and these continue to grow.

Urbanisation is a direct result of a population explosion. Since 1800 global population has risen from roughly 1 billion, to 6.5 billion in 2000 and a projected 9 billion by 2050. That population growth is linked with the Industrial Revolution that supplied the power and technology to feed those extra mouths. Cities, and especially megacities like Jakarta, Rio de Janeiro or Shanghai, are now the most visible expression of human influence on the planet (Fig. 1). The growth of cities is therefore a characteristic feature of the Anthropocene.

In 'terraforming' cities and building the dams and agricultural land that water and feed them, humans have wrought a roughly order of magnitude change in the long term rate of erosion and sedimentation (Hooke 2000; Wilkinson 2005). Paradoxically, while deforestation and changes in land use have resulted in more sediment transported in rivers, many of those rivers are now dammed, preventing the flow of that sediment to continental shelves (Syvitski 2005). Such changes may be impermanent though, and for example if human construction were to stop, nature might soon take over our constructions, reducing them to rubble over the millennia has she has done with the lost cities of ancient civilizations (Fig. 2). After 10,000 years perhaps only a layer of concrete would remain.

More profound than our buildings may be the biological and chemical signals left by humans. Thus, enhanced dissolution of increased atmospheric CO_2 in the oceans is increasing their acidity. Significant drops in oceanic pH have already occurred, and further projected decreases will stress calcifying organisms such as corals or the marine plankton that form the base of many food chains, though the biological response is complex. Ocean acidification alone may substantially change marine ecosystems over the next century and contribute to global biodiversity decline.

When did the Anthropocene begin?

The Geological timescale of Earth spans some 4.5 billion years. This vastness of time encompasses the formation of our planet, the formation of the oceans and of all our continents, and the birth of life and the evolution of the biosphere to its present complexity. For utility the vastness of geological time is divided into more manageable packages that range from the almost unfathomably long eons encompassing 100s of millions or indeed billions of years (e.g. the Phanerozoic or Proterozoic), through smaller packages of time, like the eras, that are characterised by a particular fossil record, perhaps most notably the dinosaurs and ammonites for the Mesozoic Era beginning about 250 million years ago and terminating about 66 million years ago. More fathomable for us as humans are periods of geological time, such as the Cambrian or Cretaceous. For these we can grapple with a rock record, like the chalk in the Cretaceous that was formed within these periods. Periods are divided further into epochs and ages, and the record of fossils in rocks that were deposited in these shorter intervals of time is now so well constrained that we can correlate rocks of precise age globally and reconstruct how our planet looked for a vast array of different time slices. The last period of time, the Quaternary, began just 2.6 million years ago, and has two epochs, the Pleistocene and the Holocene. The latter began only about 11,000 years ago, witnessed by changes in climate that manifest in an ice core from Greenland. The Holocene is really just the last of a series of interglacial climate states that have punctuated the severe icehouse climate of the past two million years. We may add to the Quaternary Period a third Epoch, the Anthropocene, but then we need to ask the question when did this Epoch begin and how does it differ from previous geological time?

The geological timescale that we use to subdivide the expanse of Earth history has been evolving its form for over two hundred years, beginning with the realisation of the enormity of geological time encapsulated in Hutton’s unconformities. Many of the periods of geological time, like the Ordovician, the Carboniferous or the Jurassic have been recognised for over one hundred years, and though their boundaries and precise definition are often still argued over, most divisions are drawn at fundamental changes in biota recognised in the fossil record.

Nowadays when a chronostraigraphical boundary is defined it is marked by a ‘golden spike’, and a global stratotype section and point (a GSSP) is established. This is usually placed at some major event, most notably a large and sudden turnover in fossil biota, though sometimes chemical markers are used. When stratigraphical boundaries first began to be identified in the 19th century little was known about the causes of major animal and plant extinctions, still less was known about the enormous climatic changes reflected in the geological rock record. Only much later, indeed in the latter part of the 20th century, was the geological timescale seen to reflect fundamental changes in the Earth’s climate state. This realisation came about largely through the work of the Ocean Drilling Programme that recovered sedimentary cores from marine basins globally. Once the stratigraphy of these cores was carefully reconstructed, and once correlated worldwide, they showed a precise record of climate change locked in chemical signals recovered from marine microfossils. For example, with the exception of the Cretaceous-Paleogene boundary, fundamental climate change is implicated in all of the period and epoch boundaries of the Cenozoic Era (Zachos et al. 2001). Thus, the Eocene – Oligocene boundary coincides with major ice sheet growth on Antarctica, while the Neogene – Quaternary boundary marks a fundamental change to high-frequency orbital-modulated glacial-interglacial oscillation that has characterised the past 2.6 million years.

Can we recognise a fundamental event, such as a change in climate to diagnose an Anthropocene Epoch? We know from the geological, archaeological and observed record that climate change happens naturally (Zalasiewicz & Williams 2009). These natural changes may cover enormous expanses of time, such as long-term global cooling through the Ordovician Period or through the Cenozoic Era, controlled by geological processes of long duration such as evolving continental configurations and their influence on ocean and atmosphere circulation, the building of mountain chains, or long-term changes in atmospheric composition. Dramatic and rapid changes in climate also happen naturally, such as the Paleocene-Eocene thermal maximum of 55 million years ago, apparently associated with the rapid – at least on a geological timeframe – release of carbon to the atmosphere and associated global warming. Even more rapid climate change is associated with the actions of volcanic eruptions. Thus, the eruption of Tambora in 1815 on the island of Flores in east Indonesia threw 160 cubic kilometres of volcanic ash into the atmosphere that in 1816 caused ‘the year without a summer’. The lower surface temperatures caused by the ‘global dimming’ effect of vast amounts of ash in the upper atmosphere caused widespread crop failures and famine in Europe and North America during 1816.

Changes to atmospheric greenhouse gas composition since the beginning of the Industrial Revolution, and in particular the rapid rise of $p\mathrm{CO_2}$ during the last 50 years is unprecedented. Atmospheric CO_2 levels, now at about 380 p.p.m., are much higher than pre-industrial levels of 280 p.p.m., higher than for the past 3 million years, and lie well outside the envelope of CO_2 change associated with the glacial-interglacial oscillation of the Pleistocene. This change in atmospheric greenhouse gases is recorded in both Greenland and Antarctic ice cores, locked in gas bubbles trapped in snow that fell over the past 200 years to form the ice. This change in CO_2, showing a rapid climb from the early 19^{th} century, forms one potential criterion by which to define the base of the Anthropocene and is globally correlative: the base of the Holocene Epoch is similarly defined by climate change recognised in the NGRIP ice core of Greenland (Ref.). The rise in atmospheric $p\mathrm{CO_2}$ is directly linked to an increase in global surface temperature and a commensurate range of regional climatic effects (Intergovernmental Panel on Climate Change 2007.). In some regions, most notably the Antarctic Peninsula (Fig. 3) surface temperatures have risen dramatically in the past 50 years.

While human-induced climate change is clearly a feature of at least the past 200 years, many other features of human environmental modification may provide an equally good or indeed better definition for establishing the boundary between the Holocene and Anthropocene. We might look for chemical signals of the Anthropocene, for example associated with the first metal smelting, or the invention of a range of man-made products including plastics that have left a distinctive and global trace in sediments. We might even take the atom bomb tests of the 1940s and 50s, the by-products of which are radiogenic isotopes of plutonium, americium, strontium and caesium that leave a global and extremely long-term record. These, in particular, provide a tie with the acceleration of pCO_2 rise in the atmosphere since the 1940s and with the increasing globalisation of the late 20th century (see Steffen et al. 2003). They also allow us to define a 'golden spike' in an ice core or sedimentary succession that has accumulated through the past few hundred years, to signal a precise horizon that we can correlate globally that says, before this interval of time is the Holocene and after it is the Anthropocene.

Still, the changes we have seen so far may simply be the tip of an iceberg, and changes to biodiversity for the 21st century projected by the Intergovernmental Panel on Climate Change's 4th 'The scientific basis for climate change' report (2007) may yet leave a more distinctive signal in the rock record. Like the late Precambrian metazoans of the fossil record that precede the main event of the Cambrian explosion of life, or the Permian extinctions that foretell the major Permo-Triassic boundary extinction, we may simply be in the run-up to the main event.

What might the Anthropocene tell us about the future?

The Anthropocene helps us to conceptualise that the sum effects of human activity are comparable to Epoch defining changes of the geological past. As we write in December 2009 the governments of the world are meeting in Copenhagen to try and mitigate the effects of global warming caused by greenhouse gases. China, now the largest greenhouse gas contributor to the atmosphere has a population four times that of the second greatest polluter the USA, but a level of GDP per capita only one twentieth. If all people are to live a western standard of lifestyle then something radical must happen to our technology, particularly in the way in which we generate energy. In *The War of the Worlds* H.G. Wells warned against complacency. In our discussion we have noted that the Anthropocene may not yet have begun, that we may still be approaching the critical 'event horizon'. But, the Anthropocene is certainly on the horizon. Its definition, be it marked by massive biodiversity decline, signals of chemical pollutants, radiogenic isotopes or a residue of concrete and bricks in the sedimentary rock record is still to be debated, and may involve a combination of these factors. What we can be sure of though, is that geologists visiting our world in the distant future will see a geological boundary marked by fundamental changes as great as those that define the Eocene – Oligocene boundary, or any of the other epoch boundaries of the geological past.

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Figure 1. Shanghai, China (September 2007). In 1750 the city had a population of perhaps just 50,000. Census data place the modern population at over 16 million, making Shanghai, by some definitions, the largest city in the world. Shanghai is a classic example

of the rapid emergence of megacities in the late 20th and early 21st centuries and thus a vivid expression of human influence on planet Earth.

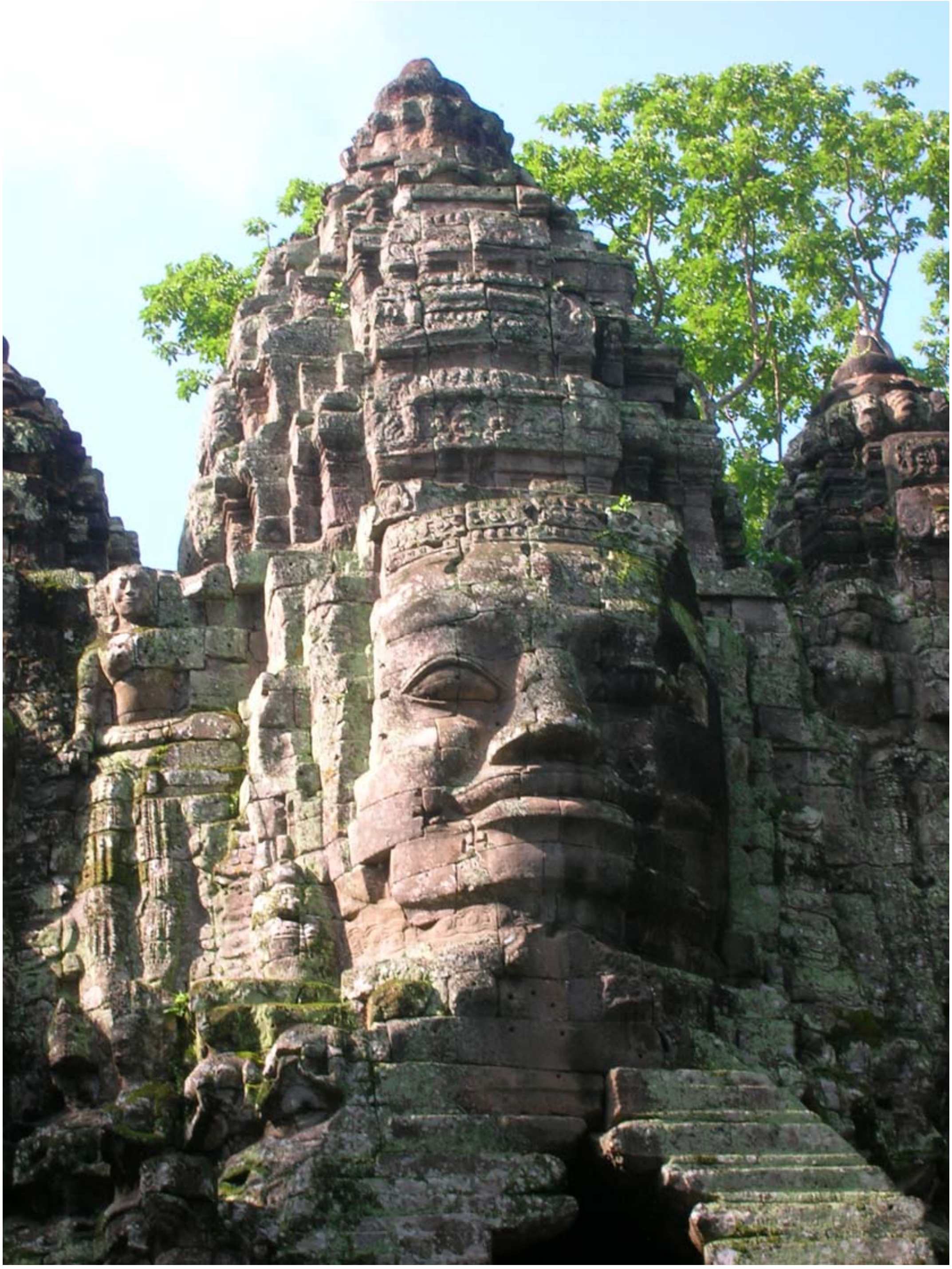

Figure 2. Angkor, Cambodia (August 2009). One of the gates to the Bayon temple complex of Angkor Tom that formed part of an urban area in the 12th and 13th centuries

that may, at the zenith of the Khmer empire, have housed more than a million people. Yet, when many of the temples of Angkor were 'rediscovered' and excavated in the 19th and 20th centuries, 500 years of neglect had reduced many of its buildings to rubble, and Angkor appeared as the classic romantic lost city. While our constructions will fall, the signal of chemical pollutants and radioactive waste that humans have accumulated over the past 200 years will leave a signal that stretches into the distant future, and one which would be identified by geologists millions of years hence.

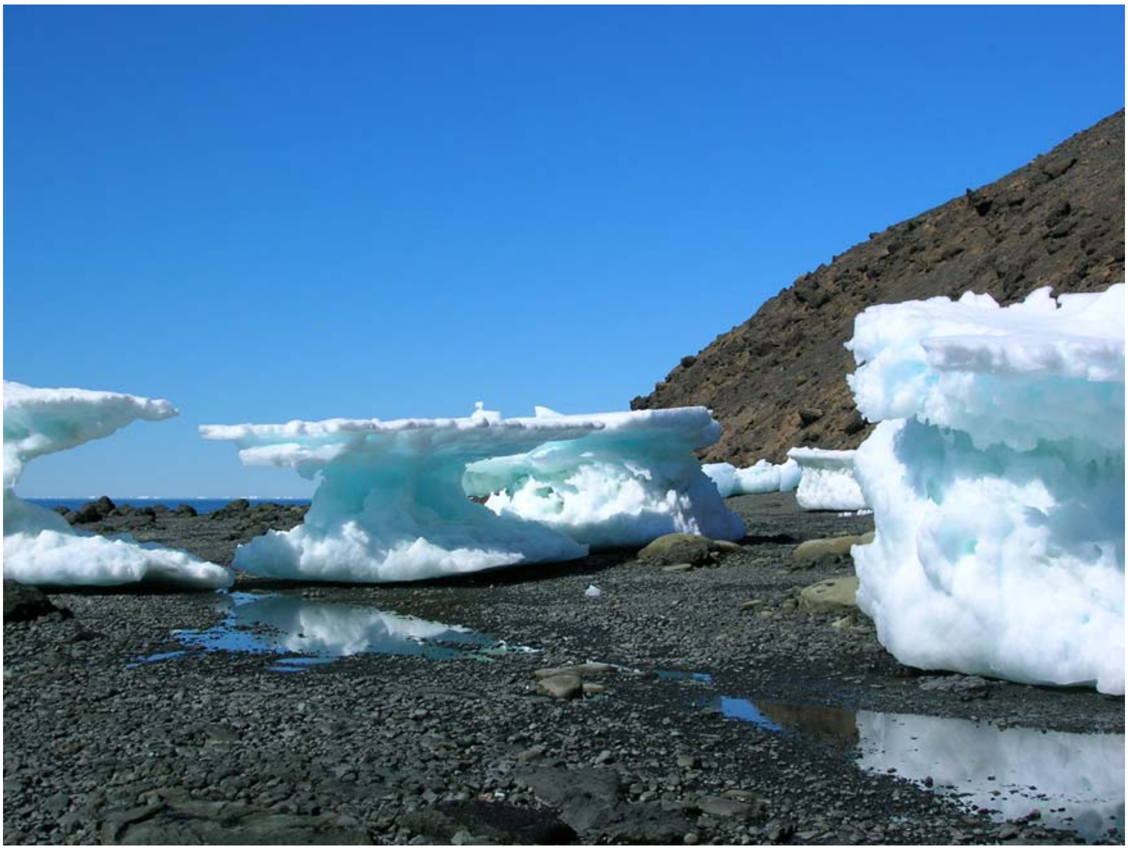

Figure 3. Stranded icebergs on the beach at East Forster cliffs on James Ross Island, northern Antarctic Peninsula (January 2006). The Antarctic Peninsula Region has seen temperatures rise by 3°C since the 1950s making it one of those regions of most rapid climate change on planet Earth.