The Anthropocene as a Geological Time Unit A Guide to the Scientific Evidence and Current Debate (edited by Jan Zalasiewicz, Colin N. Waters, Mark Williams, Colin Summerhayes)

1 History and Development of the Anthropocene as a Stratigraphic Concept

CONTENTS

We introduce here the concept of the Anthropocene as a potential geological unit of time, while noting that antecedents of this concept were sporadically present in previous literature prior to its effective inception, by Paul Crutzen, in 2000 CE. We describe how the Anthropocene compares with examples from the Geological Time Scale throughout Earth history, and demonstrate the extent to which the term has practical utility in the field of geology, in the field of natural science generally, and to the wider academic community. In this book we describe the geological Anthropocene, while this definition does not exclude other, different, interpretations of the Anthropocene that have appeared in recent years amongst other scholarly communities, particularly in the humanities. We explain here how this book will help to inform the process of producing a formal proposal for the Anthropocene as a geological time unit. Examples from the beginning of the Cenozoic Era, the Cambrian, Silurian and Quaternary periods, and the Eocene and Holocene epochs are used to demonstrate how chronostratigraphic boundaries are defined and what lessons from these can be applied to defining the Anthropocene.

1.1 A General Introduction to the Anthropocene

Jan Zalasiewicz, Colin N. Waters, Mark Williams, Colin P. Summerhayes, Martin J. Head and Reinhold Leinfelder

The Anthropocene, launched as a concept by Paul Crutzen in 2000 (Crutzen & Stoermer 2000; Crutzen 2002), has in less than two decades grown astonishingly in its range and reach amongst different academic communities. Fundamentally, it was coined to crystallise the growing realisation that human activities – or, more often, the unintended consequences of human activities – had fundamentally changed the Earth System. Hence, the patterns of behaviour of the oceans, atmosphere, land (i.e., the geosphere's terrestrial surface), cryosphere, biosphere and climate are no longer those that over 11 millennia characterised the great bulk of the epoch that we still formally live in, the Holocene. The accent on planetary processes reflected the character of the scientific community that Paul Crutzen was working in, that of the Earth System science (ESS) community, concerned most acutely with contemporary global change.

Nevertheless, the Anthropocene was explicitly described as a geological time interval, as an epoch in direct comparison to – and different from – the Holocene because of the inferred geological significance of the altered Earth System processes. The implicit hypothesis was that the Holocene had terminated, perhaps about when the Industrial Revolution started. This improvised proposal chimed with the conclusions on the nature, scale and speed of global change being reached by the ESS community, and the term soon began to be widely used in publications, matter-of-factly, as if it were already part of accepted geological time terminology. It was not formal, though, having gone through none of the extensive formal analysis, debate, agreement (via an established pattern of voting amongst appropriate stratigraphic bodies) and ratification that formal geological time terms require (and which are described fully in Section 7.8.1).

A few years after Crutzen's intervention, increasing use of the term began to be noticed by the geological community, and a preliminary analysis by a national body, the Stratigraphy Commission of the Geological Society of London, suggested that the term had merit and should be studied further with respect to any potential formalisation. This conclusion was in sharp contrast to the general response by the geological community to sporadic earlier suggestions of a 'human era', which had indeed been made since the late 18th century (Stoppani 1873; Buffon 2018). These suggestions had always been generally rejected, on the basis that the great forces of nature that drove Earth's geology were considered to operate on a vaster and longer-term scale than any kind of human impact, which by comparison was widely considered 'too puny'. The realisation, even amongst geologists, that humans could indeed significantly affect not only the Earth System parameters but, as a consequence of this, also the course of Earth's geological evolution, led to an invitation from the Subcommission of Quaternary Stratigraphy (SQS) of the International Commission on Stratigraphy (ICS) to set up a formal Anthropocene Working Group (AWG); to examine the case for formalisation; and ultimately to make recommendations to the SQS, ICS and the latter's parent body, the International Union of Geological Sciences (IUGS).

This book is the outcome of the work of the Anthropocene Working Group since 2009 in developing and testing the general case for the Anthropocene as a formal geological time unit. This work was a necessary prelude to preparing any specific formalisation proposal to the SQS, ICS and IUGS (a task that is underway). It summarises the evidence gathered in the intervening time, both by AWG members and others, for what we may here call the 'geological Anthropocene' or perhaps 'stratigraphic Anthropocene'. This distinguishes it from other interpretations of the Anthropocene that have emerged in these last few years as a range of communities, including those within the social sciences, humanities and arts, have explored this term and concept through the prisms of their own disciplines.

Thus, in our discussions of the Anthropocene to follow, there are a few things to bear in mind. Firstly, its interpretation here is non-exclusive – it does not in any way restrict (or seek to restrict) the potential use of the word in other meanings, by other communities, as has indeed been the case in the last decade (e.g., Edgeworth et al. 2015; Ruddiman et al. 2015a). Many words have more than one meaning – the word 'mantle', for instance, can be applied to part of the Earth beneath the crust, to an item of clothing, to a type of tissue on a mollusc or to part of an old-fashioned gas lamp. Sometimes the meaning of the word is clear from the context, and sometimes an appropriate qualifier needs to be used to ensure precision of communication; we suggest that such care in communication now needs to apply to the term 'Anthropocene' too.

We recognise that accepting the various material signals of the geological Anthropocene as a valid scientific outcome of stratigraphic analysis may lead, as a corollary, to analysis of the societal, cultural and political causes and consequences of the existence of a geological Anthropocene. Such a broader level of analysis is potentially of considerable importance and would involve extensive cooperation of the sciences, the humanities, the arts and society. However, it goes beyond the mandate of the Anthropocene Working Group and the scope of this book. One might use a medical metaphor, in that the characterisation and definition of a geological Anthropocene may be said to be diagnosing the condition of a planet through a particular set of symptoms, against the background of a very long family history. Such analysis of the geological Anthropocene does not, though, investigate the causes of the condition too deeply, nor does it offer any treatment plan or much in the way of a prognosis.

In a geological context, the Anthropocene is here considered as a unit of Earth history and, more than this, as a potentially *formal* unit that might become part of the ICS-produced International Chronostratigraphic Chart (which informs the Geological Time Scale). It would thus comprise a potential Anthropocene Epoch and, as its essential material counterpart and alter ego, simultaneously an Anthropocene Series, which is a unit of strata that can be dug into, sampled and – in a few cases, despite its geological youth – hit with a hammer. The value of such a designation is to make the most effective comparison between present processes and those of the deep geological past: to, as far as possible, compare like with like in making such comparisons. As the history of the Earth prior to human documentation can *only* be inferred from the rock record, this focus on material, stratal evidence is critical to comparing the modern and ancient histories of this planet and therefore to gauging the relative scale and rate of human-driven perturbation. The geological Anthropocene, therefore, has to be considered within the established rules and guidelines that apply to all other units of the Geological Time Scale. For instance, it is important that, as far as possible, its beginning (and its base, when applied to strata) is synchronous around the world (see Section 7.8).

The geological Anthropocene is not a diachronous unit of human cultural history like the Iron Age and Palaeolithic, which unfolded in mosaic fashion across the planet, or like the Renaissance (though other social science interpretations of the Anthropocene may approximate to such units). More generally, descriptions of it as a 'human epoch' are in some respects misleading. The Anthropocene is here considered as an epoch of Earth time, just like all Earth's previous epochs. It so happens that its distinctive characteristics have up until now been driven largely by a variety of human actions. But if these characteristics (such as sharply increased atmospheric carbon dioxide levels, global carbon isotope and nitrogen isotope anomalies, a biosphere modified by species extinctions and invasions, and so on – Figure 1.1.1) were driven by any other means – such as by a meteorite impact, volcanic eruptions or the actions of another species – then they would have exactly the same importance geologically.

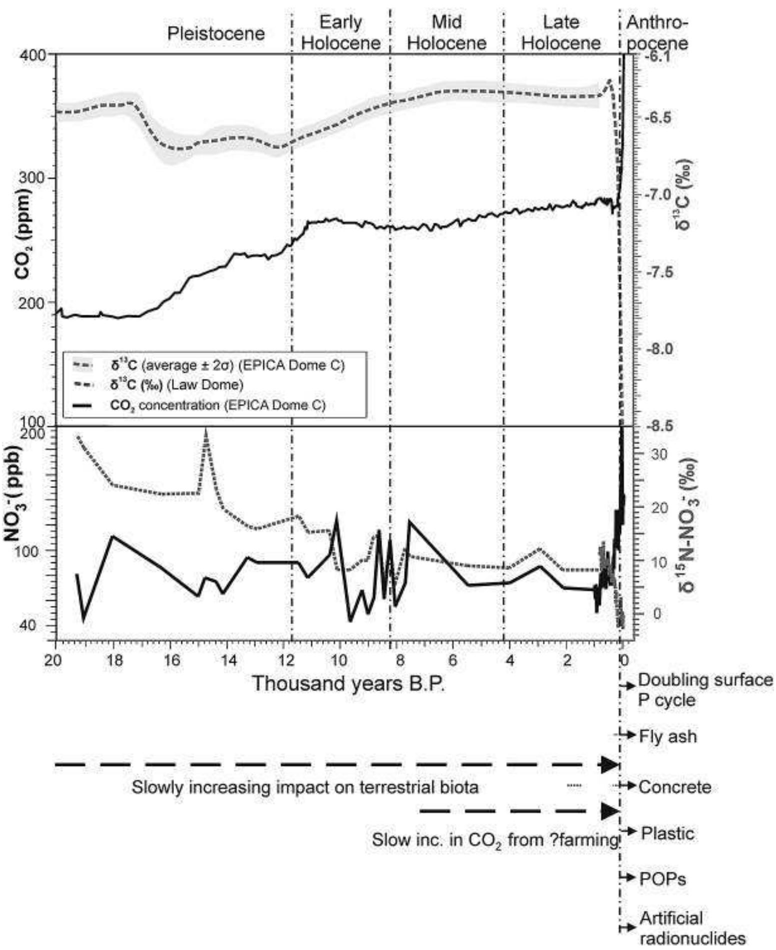

Figure 1.1.1 Trends in key stratigraphic indicators from the Late Pleistocene to the present time. Note the largely gradual change (at this scale) across the Pleistocene-Holocene boundary, the general stability through the Holocene, and the marked inflections and incoming of novel indicators that clearly demarcate a changed trajectory from the mid-20th century, identified as the Anthropocene. From Zalasiewicz et al. (2018). (POPs = persistent organic pollutants.)

Therefore, setting out these preliminary constraints of what we consider the stratigraphic Anthropocene to be and also *not* to be (constraints that are placed upon all of the units of the Geological Time Scale) helps explain the particular content and emphases that we place in this book. The Anthropocene represents a remarkable episode in the history of the Earth, a narrative that is unfinished but that has emphatically begun, and one that is of no little consequence for present and future communities. Examining it in classical geological terms will, we hope, be useful to geologists and non-geologists alike.

1.2 History of the Anthropocene Concept

Jacques Grinevald, John McNeill, Naomi Oreskes, Will Steffen, Colin P. Summerhayes and Jan Zalasiewicz

Is the modern scientific concept of the Anthropocene an old idea, dating back a century or more yet retaining its meaning and perspective? Or is it a new, paradigm-shifting conceptual novelty? This question is rendered more complicated by the diversity of the perspectives from which the Anthropocene and related ideas have been addressed, their varied interpretations and the problems inherent in making historical retrospectives (e.g., Uhrqvist & Linnér 2015).

The notion that collective human action (or 'mankind', in older parlance) is a geomorphological and geological agent altering the Earth is certainly not new in Western thought (Glacken 1956), with ideas developed by such thinkers as René Descartes and Francis Bacon around the domination or transformation of nature by humankind. But the extent to which this notion has been embedded within a context of geological and biospheric processes and deep-time Earth history – and, more specifically, in the stratigraphic nomenclature for classifying Earth history – has varied, as has scientific appreciation of our home planet as a specific and remarkable element within the solar system. The history, and indeed prehistory, of the Anthropocene concept and related ideas is still an emerging and debated topic, but it has received attention after Crutzen's (2002) early suggestions of historical antecedents in both concise (e.g., Steffen et al. 2011) and more comprehensive (Grinevald 2007; Davis 2011) accounts.

An in-depth study has yet to be written. The history of science and the development of knowledge are connected in intricate and reciprocal ways, so the appearance of a conceptual novelty and new scientific terminology is often bedevilled by misunderstanding. The new 'big idea' of the Anthropocene, as first coined by Paul Crutzen and Eugene Stoermer (2000) in the context of the IGBP (International Geosphere-Biosphere Programme) and by Crutzen (2002) and then considered by Zalasiewicz et al. (2008) in the geological context of stratigraphy, is no exception (Hamilton & Grinevald 2015).

The ancients sometimes pondered how humans relate to their world, as in Lucretius' suggestion of an Earth made weary through the weight of a growing human population. But perhaps the first significant reference in the Western world is within an influential work in which the Earth's history was, for the first time, systematically chronologically described on the basis of empirical geological evidence. This is Buffon's *Les Époques de la Nature*, published in 1778 (Roger 1962; Buffon 2018; see also Heringman 2015). In this pioneering book, the seven 'epochs' represent distinct phases in Earth history, ranging from its initial cooling to the formation of the oceans and the lowering of sea level, the weathering of primordial rocks and the deposition of sedimentary strata, and the origin and progression of successive, different forms of life. The 'seventh and last epoch – When the power of Man assisted the operation of nature' is described as one in which humans not only are present but, as 'civilised humans' (placed by Buffon in overt opposition to 'savages'), are modifying key Earth processes such as regional temperature and precipitation by altering vegetation patterns and burning coal. In attempting to describe how key planetary mechanisms (crust formation, sea level, volcanism and so on) might be interlinked and how they can evolve through time, Buffon was a pioneer of Earth history, and the late (in Buffon's chronology) addition of human participation in Earth history is placed within this same intellectual framework. Buffon, like James Hutton, Joseph Black, Adam Smith and James Watt, was a natural philosopher of pre-industrial Europe, a man of the 'Age of Enlightenment' and one of many thinkers considering the place of humans in Earth history (see Rudwick 2005, 2008).

The idea of 'man' as a geographical and geological agent arose in a succession of geological and related naturalist publications in the mid- to late 19th century. The Welsh geologist and theologian Thomas Jenkyn (1854a, b; mentioned by Lewis & Maslin 2015) also wrote of a 'human epoch' that he referred to as an 'Anthropozoic' that would leave a future fossil record. The term Anthropozoic was also used by Haughton (1865) and the Italian abbot and geologist Stoppani (1873; quoted by the US ambassador in Italy; Marsh 1874) and was rediscovered by William Clark in the 1980s (Clark 1986, quoted by Crutzen). Stoppani observed that humans, since the rise of Christianity, were changing not only the present but also the future of the Earth. The roles of humans and environmental change in the geology of the recent past were later to be conflated with the classification of geologically recent strata as the Holocene (a term proposed to replace Lyell's 'Recent' by Paul Gervais in the 1860s and adopted after the Third International Geological Congress of 1885), in which the geologically defining forces were seen to be marked by post-Pleistocene glacial warming and sea-level rise, but in which it was recognised that locally abundant human activities and traces formed part of the characterisation.

The entire Quaternary Period (Gibbard & Head 2009), broadly representing the Ice Ages (see Section 1.3.1.5), was recognised as the time when the human genus diversified (albeit mostly remaining ecologically and geologically insignificant) and was termed the Anthropogene (sometimes transcribed as Anthropocene) by some early- to mid-20th-century Soviet geologists and geochemists. While the Anthropogene was essentially a synonym for the Quaternary (Gerasimov 1979), Piruzyan et al. (1980; quoted in Grinevald 2007) noted the following:

> The notion that mankind was becoming a power of geological scale was, by the beginning of the 20th century, clearly expressed by A. P. Pavlov in Moscow and, independently, by C. Schuchert in New Haven. They interpreted in a new way long-known facts on the changes in the environment caused by human activities, coming to the conclusion that their manifestations characterised the beginning of a new geological era. Ideas on the new geological era – 'Psychozoic' according to Schuchert, 'anthropozoic' according to Pavlov – were developed in detail by V. I. Vernadsky.

A focus on the changes that humans specifically were making had been first documented by George Perkins Marsh in his classic book *Man and Nature* (1864), which was retitled as *The Earth as Modified by Human Action* in the second edition of 1874. Marsh's study was couched in environmental or geographical rather than geological (or stratigraphic) terms, reflecting his posthumous status as 'North America's first conservationist' or 'Prophet of Conservation' (Lowenthal 2000). But his themes and influence were overtly restated and examined in later meetings and publications (Thomas 1956; Nir 1983; Orio & Botkin 1986; Turner et al. 1990; Naredo & Gutiérrez 2005). A classically geological analysis by Sherlock (1922) systematically documented the lithostratigraphic dimension driven by mining, building and related activities, assembling statistics on different types of mineral production and rock and earth movement and considering not only the effects in sedimentological and geomorphological terms but also geochemical effects, not least following Arrhenius (see the next paragraph) in linking coal burning to previsaged climate warming (see also Shaler 1905).

While Marsh and others, including Thomas Jefferson, had realised that human changes to Earth's plant cover led to changes in the temperature of the air, John Tyndall had demonstrated in the 1860s that the minor gases of the air, like water vapour, carbon dioxide, methane and ozone, had the power to absorb and re-emit long-wave radiation, meaning that fluctuations in their abundance could change the climate (Tyndall 1868). Arrhenius had calculated 30 years later that doubling the amount of CO_2 in the air would warm the planet by about 6°C (Arrhenius 1896). By 1908 he had modified that figure to 4°C and noted that the burning of coal by industry would emit enough CO_2 to measurably warm the atmosphere (Arrhenius 1908). He thought that would be no bad thing – humans would benefit from living in a warmer, more equable climate, and rising warmth and CO_2 would stimulate plant growth, providing more food for a larger population and even preventing the occurrence of another glacial period. This kind of human impact on the planet was well beyond that envisaged by the likes of Marsh or Sherlock. But it was not until the mid-20th century that scientists were able to build on Arrhenius's findings and become fully aware of the growing human impact of changing atmospheric chemistry, not least because the technology to provide us with the full spectrum of CO_2 in the atmosphere was not available until the mid-1950s (Plass 1961). For more on CO_2 and climate, see Section 6.1.

More or less simultaneously, influential conceptual developments under the same terms of 'biosphere' and 'nöosphere' were made by two French Catholic visionary thinkers: Pierre Teilhard de Chardin, then professor of geology, and Édouard Le Roy, a mathematician turned philosopher and Bergson's successor at the Collège de France. Another significant contributor was the remarkable Russian geoscientist, Vladimir I. Vernadsky, a hugely influential member of the Saint Petersburg Academy of Sciences, who was then staying in Paris. The nöosphere (or anthroposphere, including the technosphere) denoted accelerating human transformation of 'the face of the Earth' (a term derived from the massive and widely read early-20th-century geological synthesis of Eduard Suess). These various ideas of Teilhard, Le Roy and Vernadsky generated a range of interpretations (and confusions) in subsequent years, mainly after the Second World War (WWII) and the birth of the Nuclear Age. Teilhard disagreed with Vernadsky's meaning of the 'biosphere', which both took from Suess. Teilhard's evolutionary view of life and man on Earth was ignorant of Vernadsky's biogeochemical perspective, and he probably never read *La Biosphère*, the 1929 French translation of Vernadsky (1926, in Russian) – at least, he never quoted it in his writings. In general, Vernadsky's biogeochemical teachings and his own ambitious concept of the Earth's biosphere in the cosmos were commonly ignored (Vernadsky 1998).

The term 'nöosphere' was adopted by Vernadsky only after Le Roy's books of 1927 and 1928 (Vernadsky 1945, 1997). It was originally seen as a direct offshoot of the biosphere, a term and notion briefly coined by Suess in his 1875 book *Die Entstehung der Alpen* (The Origin of the Alps) and restated in 1909 in the final chapter, 'Das Leben' (Life), of his great work *Das Antlitz der Erde* (The Face of the Earth). The term 'biosphere' was adopted by Teilhard and Le Roy, with a restricted biological meaning, and developed in a global biogeochemical perspective by Vernadsky (1926; see 1998) to represent not just the sum total of living matter (or biota, according to Teilhard) on the Earth's rocky crust, but an evolving complex system representing the dynamic interaction and co-evolution of life, crustal mineral matter, ocean, atmosphere and energy (mainly from the Sun). It was this geobiological system that Vernadsky viewed as being changed and perturbed by growing human activities, particularly technical and scientific development (Vernadsky 1924, 1945, 1997).

Vernadsky's ideas foreshadowed many of those developed by James Lovelock and Lynn Margulis (1974) in the 'Gaia hypothesis', specifically that life acts together as a system to modify and regulate surface conditions on Earth. Lovelock, like most Western scientists, only became aware of Vernadsky after he had developed his own ideas (Grinevald 1987, 1988). As in the case of Plass (1961) and the measurement of the spectrum of CO_2 in Earth's atmosphere in the 1950s, Lovelock's Gaia concept also depended on the development of a new technology, in his case for the measurement of gases in the atmospheres of other planets, in the search for signs of life. The atmosphere of a planet with life would contain a cocktail of gases out of equilibrium with one another, much like Earth's, while a planet without life would contain an atmosphere dominated by gases like CO_2, as on Mars and Venus (Lenton 2016). In due course, Lynn Margulis was instrumental in the United States for the publication in New York of a first 'complete annotated edition' of Vernadsky's *The Biosphere* (Vernadsky 1998), significantly cited by Crutzen and Stoermer (2000) and Crutzen (2002).

Over the 20th century, the epic scale of Earth history (e.g., Hazen et al. 2008; Lenton & Watson 2011; Zalasiewicz & Williams 2012) was becoming progressively clearer – not just its multi-billion[1]-year duration, as resolved by radiometric dating, which allowed the time necessary for the evolution of many successive life forms by Darwinian evolution, but also the profound nature of geological change. The plate tectonics revolution (Oreskes 1999; Oreskes 2003) showed that even ocean basins and mountain ranges were ephemeral features on a planetary timescale, while detailed geological studies showed that rare, extraordinary volcanic outbursts (far greater than anything in recorded human history) and meteorite impacts could fundamentally perturb the Earth System and lead to mass extinctions. Geologists also came to understand that the evidence of the last few million years, of the Ice Ages, revealed that present-day temperate landscapes were formerly buried under kilometre-thick sheets of ice, while global sea-level changes reached amplitudes of ~130 m, roughly twice the amount of sea-level rise that would happen if all of the Earth's present ice were melted (see Chapter 6 for a fuller discussion).

Small wonder that, until recently, the great majority of geologists thought human impact on the geology of the planet (if they thought of it at all) to be trivial and fleeting by comparison with these more obvious large-scale geological events. Collations of the physical impact on the Earth's geology (in terms of such things as volumes of raw material excavated) by such as Sherlock (1922) were impressive, but the resulting constructions were generally regarded as temporary, easily erodible structures that (once humans were no longer present) would simply be recycled back into the Earth by processes of erosion and sedimentation. There was also a tendency to regard geology as ending as human history began and giving way to disciplines such as anthropology, archaeology and written history (cf. Finney 2014).

One might take the opinions of the influential North American geologist Edward Wilber Berry (1925) on the Psychozoic as typical of widely held opinion in the international geological community through much of the 20th century. While admitting the 'magnitude and multifarious effects of human activity', he said that these were 'scarcely of geological magnitude' and that the Psychozoic was 'not only a false assumption, but altogether wrong in principle, and is really nurtured as a surviving or atavistic idea from the holocentric philosophy of the Middle Ages'.

Widespread acceptance that humans could profoundly alter the course of the Earth's geological evolution – and that geology (particularly stratigraphy) as a discipline reached into the present – emerged only slowly and fitfully, in the post-WWII years. Significant change in opinion was associated with such developments as the emergence of Earth System science, closely associated with the development of atmospheric science and the rise of biogeochemistry, and the ambitious International Geosphere-Biosphere Programme (IGBP) in the later part of the 20th century (see the 'Reflections on Earth System Science' by IGBP's leaders published in *Global Change*, Rosswall et al. 2015). These had built on earlier developments in the post-WWII years. Fairfield Osborn's book *Our Plundered Planet* wrote of 'man as now becoming for the first time a large-scale geological force' (Osborn 1948, p. 29) and included a chapter on this theme, with explicit reference to Vernadsky's work. The role of the early debate on the first Meadows report to the Club of Rome, *The Limits to Growth* (see Georgescu-Roegen 1975), was significant here, too, as illustrated by the emergence of Georgescu-Roegen's bioeconomic paradigm, in which he suggested that natural resources are irreversibly degraded once they are exploited in economic activity, and in which he developed concepts of ecological economics and industrial ecology.

These developments led to a growing appreciation of human impact (e.g., Turner et al. 1990), not so much upon the physical structures of the planet but rather on its chemical and biological fabric, with such phenomena as climate change and biodiversity loss

[1] Billion is used throughout this book as a thousand million.

coming to the fore. As a further factor, both the United States and the USSR started paying much more attention to the 'environment' as a theatre of warfare and pouring large amounts of funding into atmospheric and oceanic sciences. Given that such processes could be geologically long-lived (as regards climate change) or even permanent (as regards species extinctions), realisation grew of the scale and potentially lasting nature of human-driven perturbations.

Suggestions of 'geological' terms to describe this global change reappeared. Andrew Revkin published the term 'Anthrocene' in a 1992 book on global warming (Revkin 1992). The biologist Michael Samways (1999) coined the term 'Homogenocene' to encompass the increasing global homogenisation of animal and plant communities through widespread species invasions. The oceanographer Daniel Pauly (2010) came up with the term 'Myxocene' to describe his projection of future oceans dominated by jellyfish and microbial slime.

However, it was the term Anthropocene that began to take hold, initially within the Earth System science community. In February 2000, the term was offered on the spur of the moment by Paul Crutzen, the Nobel Prize–winning atmospheric chemist, at a meeting of the IGBP Scientific Committee in Cuernavaca, Mexico. Becoming progressively impatient at discussion of global change in the Holocene, he broke into the discussion, saying that we were no longer in the Holocene but in (and here he improvised) . . . the Anthropocene. Part of the rest of the meeting was taken in discussion of this idea; afterwards, Crutzen researched the term, found that it had been used for some years informally by a lake ecologist, Eugene Stoermer, and invited him to join him in publishing the term (though the two men never met). It was published in 2000, in the *IGBP Newsletter*; the article was invited and edited by IGBP executive director and newsletter editor Will Steffen, who had been present at the Mexico meeting. Two years later, Crutzen published a brief, vivid one-page article on the term in *Nature* in 2002, which gave the term wide visibility. He suggested that the Anthropocene began with the Industrial Revolution.

Continued research within the IGBP community led to the recognition that the time since ~1950 CE has without doubt seen the most rapid transformation of the human relationship with the natural world in the history of humankind (Steffen et al. 2004). At a 2005 Dahlem Conference on the history of the human-environment relationship, in which Crutzen participated, the sharp upward inflection of many trends of global significance in the mid-20th century was recognised as the 'Great Acceleration' (Hibbard et al. 2006). That term was first used in a journal article in 2007 (Steffen et al. 2007), in which it was regarded as a 'second stage' of the Anthropocene, following the Industrial Revolution.

The term Anthropocene began to be widely used and further analysed, particularly within the IGBP-based community (e.g., Steffen et al. 2004). In publications, the term began to be used as if it were a formal part of the Geological Time Scale, without inverted commas or other such qualifications – but it was not formal, and to this time it remains informal.

In response to the growing visibility and use of the term, the Stratigraphy Commission of the Geological Society of London considered the Anthropocene as a potential addition to the Geological Time Scale. Although it is a national body, not an international one, and has no power of formalisation, it published a discussion paper (Zalasiewicz et al. 2008) signed by a majority of commission members (21 out of 22) suggesting that there was geological evidence to support the term and that it should be examined further with respect to potential formalisation.

There followed an invitation from the Subcommission on Quaternary Stratigraphy, a component body of the International Commission on Stratigraphy (the body responsible for maintaining the Geological Time Scale, more technically known as the International Chronostratigraphic Chart), to set up an Anthropocene Working Group (AWG) to examine the case for formalisation. The AWG has been working since 2009 and has published two volumes of evidence (Williams et al. 2011; Waters et al. 2014), together with a number of individual papers on particular aspects (e.g., Edgeworth et al. 2015; Waters et al. 2015, 2016, 2018), as well as responses to emerging critiques of the Anthropocene from both the stratigraphic (Zalasiewicz et al. 2017d and references therein) and other communities (e.g., Zalasiewicz et al. 2018). This book represents a summary of these and related studies on the Anthropocene.

The AWG process was (and remains) in many ways novel as regards the assessment and determination of stratigraphic units – particularly in view of its inverted sequence of evidence and deductions (Barnosky 2014). Instead of stratigraphic names (such as the Cambrian, Cretaceous and so on) emerging from prolonged study of ancient strata, the Anthropocene Working Group was considering a concept that had emerged from another (albeit related) field of science and then determining whether it could work in both geohistorical terms (for example, as an Anthropocene Epoch) and stratal terms (to enable a time-based material unit of strata – an Anthropocene Series – to be recognised and correlated across the Earth) (see Section 1.3 for explanation of this distinction). The group also had to consider human phenomena and timescales as well as non-human, geological ones – and hence needed to include representatives of archaeology, ecology, oceanography, history, law and so on. There was also the matter of the very short timescale as compared with the million-year-scale units normally considered by stratigraphers (although the establishment of the Holocene had already provided an epoch-scale unit measured in centuries and millennia rather than in millions of years).

The stratigraphic examination of the Anthropocene has taken place in tandem with its exploration as a key concept by a wide variety of other disciplines, many from outside the Earth sciences and including the social sciences, humanities and arts (e.g., Hansen 2013; Chakrabarty 2014; Davies & Turpin 2015; Latour 2015; Angus 2016; Bonneuil & Fressoz 2016; Davis 2016; McNeill & Engelke 2016; Clark & Yusoff 2017; Hamilton 2017; see also McNeill 2001). The Anthropocene has been seen both as providing some measure of, and deep-time context to, human 'environmental' change to the planet and as integrating the effects of a wide variety of environmental change that are commonly considered more or less separately (such as climate change, biodiversity loss, ocean acidification). That integration is made via extension of the use of the 'multi-proxy' approach typical of modern stratigraphic studies, and it may be related to such compilations of global environmental change as in the 'indicator graphs' of Steffen et al. (2007, 2015) and the planetary boundaries concept (Rockström et al. 2009; Steffen et al. 2016).

Following several years' work, the AWG provided its initial findings and recommendations to the 2016 International Geological Congress held at Cape Town (Zalasiewicz et al. 2017d). It found, overall, that the Anthropocene possesses geological reality consistent with a potential formal time unit and that a proposal towards formalisation should be made, at the hierarchical level of epoch/series with a boundary to be defined by a GSSP (Global Boundary Stratotype Section and Point) at some level at or around the mid-20th century (Wolfe et al. 2013; Steffen et al. 2015; Zalasiewicz et al. 2015b; Waters et al. 2016). 'Bomb test' radionuclides were suggested as the primary marker.

Support for formalisation has not been unanimous within the stratigraphic community, and detailed and searching questions have been asked as to whether it is appropriate to consider a unit so geologically brief and with so many novel features as a part of the Geological Time Scale (e.g., Finney 2014; Gibbard & Walker 2014; Smil 2015; Finney & Edwards 2016; for responses see Zalasiewicz et al. 2017d). And there have been suggestions that the Anthropocene should not be defined in geological terms but should become a term of the social sciences – or be suppressed because it is inappropriate to other disciplines (Ellis et al. 2017;