# III. ESSAYS ON BIG HISTORY

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## The Change We can Believe in: Ten Facts about the Evolution of the Earth-Life System and their Relevance to Current Global Environmental Change

*Nigel C. Hughes*

### Abstract

*For the first time in human history, what we believe about the past of the Earth has direct implications for our future. If we are to make responsible choices about global environmental change, we must understand what the Earth's prior history of physical and organic evolution says about how the planet and its inhabitants have co-evolved in the past, and be able to relate these insights to current condition. The Big History movement is an important bridge between scientific understanding of this past, varied views of humanity's place in Earth history, and practical environmental issues that affect our daily lives. If Big History is to gain serious traction, the movement must emphasize linking lessons from the past to the choices we must make as a global society. This paper presents ten facets of Earth history that contextualize some current issues concerning global change and species extinction within a Big History perspective. I argue that, although extinction has played an important role in shaping the evolutionary history of life and we are here partly because of it, the fact that almost all species that have ever lived are extinct cautions against a passive response to global climate and environmental change.*

The origin and destination of a journey are critical components of any travel, but they are not the journey itself. Likewise, although we are naturally drawn to events associated with the origin of the Universe, and to understand our unique place within it, neither of these issues are, in my opinion, the meat of the Big History movement. We are drawn to such terminal events because they appear seminal, and also because they are temporally and spatially comprehendible to us. Even though we may find the behaviours of subatomic particles bizarre and unfamiliar, they are at least distinctly odd. Black holes fascinate because reassuringly they reconnect the realms of the universal and the subatomic: they link the start and the finish. Likewise, we are intrigued by

*Evolution: A Big History Perspective 2011 232–238*

the first few millennia of this Universe's history because the temporal scale and rate of change are more familiar to us than the huge interstellar distances or the eons of geological time that constitute the real journey of Big History. That journey concerns concepts we experience routinely in our own lives, time and distance, but which are expressed at scales we find disturbingly incomprehensible.

An irony of these terminal events is that they are among the least important when it comes to accessing the societal significance of Big History as a discipline. From that perspective, what is vital is the attempt to contextualize our actions in the place and at the physical scale over which our personal choices have consequence. In this regard, the central issue of Big History is whether or not the Earth has an extensive past that can be read and interpreted from the record it has left behind, and from its current state. This issue is central, because it reflects a fundamental choice. If we accept that the Earth has a history that we can interpret using a science-based approach, then we can hope to learn from the past and use it to predict what may happen in the future. If we reject this history, as does a substantial proportion of the world's population, then that history has no relevance to us. We are thus living during a unique time: for the first time in the history of our species, what we believe about the age and history of the planet and life upon it has critical significance for our future as a species.

Accordingly, the realms in which Big History is most relevantly characterized are those of geology and biology, two disciplines that are becoming increasingly intermeshed as we learn how closely the Earth's physical and biotic environments are, and have been, interwoven. These issues relate intimately to the journey of history, rather than to its origin or current destination. They take place over time scales that are impossible for humans to conceptualize or relate to in any realistic sense. Nevertheless, it is these events that set the scene and hold the promise for understanding our own future on this planet. Below I will present ten of the most striking features of Earth's history that are, in my view, critical knowledge for those making responsible political choices concerning our collective future.

*1. Many Earth-like planets.*

Almost every week the world's leading scientific journals, *Nature* and *Science*, discuss new successes of the search for planets beyond our solar system. Given the numbers of such planets already detected, and the numbers of stars in the Universe, it is probable that other Earth-like planets exist in appreciable numbers, and that some of these planets support, or have supported, life.

*2. The Earth's surface has been continuously dynamic.*

Our planet stands out from others in our solar system in many ways, the most obvious of which is the peculiar chemistry of its fluids in the oceans and the atmosphere. More subtle, but even more telling, is that fact that the surface of the planet is littered with the record of the planet's active history – testified by the layers of rock strata (Zalasiewicz 2008). Each of these layers is a record of the dynamic interaction between the consequences of heat energy released by radioisotopic decay within the interior of the Earth and those of heat energy from the Sun that is absorbed at the Earth's surface. It is this interplay that has fostered the extended proliferation of life on the planet. Without it, life might have been initiated, but it would have been hard or impossible to maintain over the long term.

*3. Life began early in Earth's history.*

The dynamic nature of the Earth's surface means that much of the record of its history has been eroded and recycled. Hence, the longer ago an event took place, the lower the probability that a record of that event has been preserved today. This notwithstanding, some of the oldest rocks on Earth contain evidence for the presence of living organisms, perhaps as old as 3.5 billion years or even older (Schopf 1993). One implication of this early origin of life, though based on the sole example of our own planet, is that the evolution of life on a planet of this kind may not be highly improbable.

*4. Planetary and organic history is intimately linked.*

The chemistry of the atmosphere and oceans of our planet has changed slowly, intermittently, but persistently over the 4.6 billion years of Earth history. Life has played a defining role in achieving these changes, and most particularly in altering the amount of free oxygen available in Earth's surficial fluids (Scott *et al.* 2008). The interplay between life and the physical environment is highly complex – major changes in the system have coincided with dramatic changes in the physical environment, such as major reorganizations of the continents, or the times at which large portions of the Earth's surface were covered in ice. As these events are highly complex, it is commonly hard to constrain their precise causal sequences, and thus to know how likely similar events are to have occurred on other Earth-like planets.

*5. Microorganisms only for a vast majority of Earth's history.*

Despite points 3 and 4, we do know that complex multicellular life only became established on Earth after an extremely extended period of time, during which both microorganisms and planetary conditions evolved in tandem. It took the Earth a vast amount of time before complex organisms made from multiple cells with differentiated functions could operate viably, and before evolutionary novelties such as sexual reproduction enabled more rapid spread of complex biological innovations. We do not yet know, in detail, the sequence of events that lead to multicellularity, but we do know that it took a vast amount of time to appear and that it was associated with a significant rise in the volume of atmospheric oxygen. It is possible that other worlds harboring ancient life have yet to evolve multicellularity and may never do so because they have not experienced the unique combination of physical and biotic changes that the Earth has.

*6. Geologically rapid establishment of complex life.*

Once multicellular life became established on Earth, complex forms and ecologies evolved relatively quickly over a period of about 100 million years or less (Hughes 2001). At the end of this period, ecosystems obtained animals structured in ways broadly similar to those we see around us today. Both the array of forms and the diversity of types rose rapidly, reaching in the shallow oceans (the site of the most complete fossil record) a rough plateau of diversity relatively quickly, by about 450 million years ago. This plateau has been since maintained at an approximately similar level of diversity, although there has been a series of geologically rapid major diversity drops superimposed upon it, followed by more temporally prolonged intervals of the recovery of diversity. The diversity drops are called 'mass extinctions' (Raup 1991).

*7. Mass extinctions, their causes and consequences.*

Five major drops in marine diversity have been recognized since the advent of abundant complex life in the oceans some 550 million years ago. These are times when the numbers of species going extinct were orders of magnitude higher than at normal 'background' extinction rates. The driving mechanisms for these extinctions have varied, but they all appear to be related to significant changes in physical conditions on a planetary scale (*e.g.,* Finnegan *et al.* 2011). These include the meteor impact that terminated the dinosaurs and many other organisms about 65 million years ago, but also more indigenous causes, such as geologically rapid changes in ambient temperature conditions, as well as associated variations in the mixture of gases in the atmosphere and oceans. Such mass extinctions are characterized by sharp and permanent changes in the species compositions before and after the events. The larger the mass extinction, the more drastically different is the new biota that succeeded it. Accordingly, mass extinctions have had a major effect on the architecture of complex life. The removal of incumbent forms that dominated ecological systems prior to the extinction also provided opportunities for new evolutionary innovations to become widespread – the rise of the mammals following the demise of the dinosaurs is a classic example of this.

*8. Drastic environmental change was sometimes rapid in ancient times.*

From the point of view of our own choices, the most prescient fact we are learning about this record of past change is that, in certain circumstances, ancient and drastic environmental change apparently took place on the timescale of a human life. An example is the series of apparently extremely rapid changes in the values of the various isotopes of carbon that took place in a series of pulses that are recorded in the Jurassic rocks of Yorkshire, and which were accompanied by a series of extinctions that each apparently eliminated over 50 % of the local marine animal life (Kemp *et al.* 2005, but see also Wignall *et al.* 2006). These changes appear to have been related to the rapid population of the ocean and atmosphere by isotopically 'light' carbon atoms that had previously been locked away from the oceans and atmosphere in the form of hydrocarbon resources stored in the Earth's shallow crust. A likely candidate source for this light carbon may have been the rapid release of methane gas from resources of ‘methane ice’ (also know as ‘clathrate’). Similar resources occur today in huge volumes on the shallow ocean shelves and in the tundra, and – if similar resources occurred in the Jurassic – then their rapid destabilization could have yielded sufficient ‘light’ carbon rapidly enough to explain the isotope signal and its warming-related extinction. These Jurassic pulsed changes in isotope values, each of which probably took 100 years or less to achieve, were apparently related to cyclical, astronomically induced episodes of climatic warming. They were not caused by humans, who did not evolve until more than 150 million years later. Nevertheless, they suggest that the Earth has been vulnerable to drastic environmental change, which occurred on timescales that we can relate to in our own lives. Extremely rapid warming at the end of glacial cycles is another example (Alley 2000). The key point about these ancient changes is that they demonstrate that scientific understanding of the past is critical for predicting our immediate future. As huge and unstable accumulations of methane ice exist on the ocean shelves today, the global warming we are causing via our increasing carbon dioxide concentrations could trigger the release of large volumes of the far worse greenhouse gas methane. The effect of rapid methane release on the present global environment would be immediate and drastic, just as it appears to have been during the Jurassic.

*9. The knife-edge balance of biological diversity.*

According to some estimates, 99.9 % of species that have ever lived on Earth have gone extinct (Raup 1991). Hence, we live on a knife-edge balance in which the excess of events of species origination just fractionally exceeds the number of species that have gone extinct. This is a salient fact amidst talk of ‘adaptation’ as a survival strategy in a time of global change. While adaptation during evolution has allowed us the privilege of being here, far more species leave no descendants at all than the few that have gone extinct through evolving into something else. It is both true and ironic that we owe our own evolution to mass extinction, but it is equally important to realize that, as a living species interested in our own survival, it is in our best interest not to cause rapid environmental changes, the full impacts of which we cannot yet predict with confidence.

*10. Change we can believe in.*

Everyone reading this will be aware of the issue of global change, but some may feel challenged by it. Few can evaluate or articulate the arguments cogently, because to do so requires in-depth understanding of the way the Earth works, and this draws on a vast array of scientific knowledge. I for one, despite 30 years of training, feel well versed only in a few related topics. But the bottom line of global change is straightforward. Firstly, the scientific debate about whether human-induced global warming is happening was over about ten years ago, despite what some politicians would prefer. Global warming is happening, and it is happening fast. Secondly, this should not be a surprise to anyone reading this article, because the fundamental basis of global warming is very simple. We are taking vast numbers of carbon atoms that the Earth, over hundreds of millions of years, has locked away as hydrocarbons (coal, oil, natural gas, clathrates, *etc*.) in its crust, and are releasing them back into the oceans and atmosphere in a mere 150 years. When in the atmosphere, these atoms in their various molecular combinations cause warming through the greenhouse effect. This current rate of carbon transfer to the atmosphere is extraordinary in Earth history and can only be expected to lead to dramatic and rapid consequences, some of which can be predicted, but others cannot. As extinction rates now match those of previous mass extinctions, we are in the midst of a sixth mass extinction (Barnosky *et al.* 2011), but this one is ultimately induced by a biological change – our own actions – not primarily by a physical cause. The largest threat is that the warming we are causing at present initiates a feedback chain of events that rapidly accelerate with far worse consequences. Such rapid changes have occurred in the past, and we know that the same potential triggers occur on Earth today.

Although some colleagues might quibble with the tone of some of what I have presented above, the factual basis of the record is very strong. This has not prevented misstatements about the consequence of deep history. For example, it has been suggested that global warming is less worrying than it might seem, because the Earth teemed with life during the Cretaceous period some 100 million years ago, during which temperatures were warmer than anything we know today or expect to achieve soon, in spite of our best efforts. However, this rosy outlook overlooks the simple fact that despite the warm conditions of the Cretaceous, we were not there to experience them. Worryingly, only a tiny fraction of the species that were living during the Cretaceous are still represented in today's biota, for it is extinction, not survival, that is the motif of life's history. The challenge of human-induced global warming and other self-induced changes is not that all life on Earth will go extinct, or even that complex life will vanish. It is merely that, if unchecked, we will not be able to sustain the sort of societal structures and comforts we have become accustomed to, and that collapse of our society could precipitate our ultimate demise via vulnerability to additional calamities.

Hence, the choice before us, and the challenge for the Big History movement, is quite stark. In my own classes, I find significant numbers of students who do not accept the overwhelming evidence that the Earth is ancient and that it has a history that can be interpreted scientifically with significant implication for our own times. Their motivation is adherence to some version of Abrahamic tradition (Jewish, Muslim or Christian) that they feel requires a short Earth history. When I have engaged such students in discussion, some have appealed to democracy as justifying equal assertion of multiple views. Alternative views are certainly legitimate within their own frames of reference, but science itself is not democratic. Ideas offering strong explanatory insights into natural phenomena are retained, while those that do not are rejected. Many more students simply do not make the connection between what they learn in any science class with other part of their lives. This is where, in my opinion, Big History has a potentially important role, particularly when the scientific perspective on our place in nature is respectfully contrasted with other expressions of our origins and history. This is a path by which we may link what science tells us about our place in history with the reality of the choices we make in our daily lives.

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