The geology behind the Anthropocene

Jan Zalasiewicz

Professor and Course Director for Geography-Geology and Geology with Palaeobiology degrees in the Geology Department of the University of Leicester. Jan Zalasiewicz is a specialist in mudrock processes (sedimentation, diagenesis and low-grade metamorphism) and early Palaeozoic and Quaternary stratigraphic analysis, including study of the Anthropocene concept. His recent publications include (with M. Williams) *The Goldilocks Planet: An Earth History of Climate Change*, Oxford University Press, 2012, and *The Planet in a Pebble: a Journey through Earth History,* Oxford University Press, 2010.

Summary

Stratigraphic geology arose as an ever more sophisticated classification of rock units, mainly to extract resources, and of time and events in Earth history. The former played a large role Earth's recent transformation by humans, and the latter may be used to gauge the scale of change, by comparing present change (all around us) with changes in the deep past (preserved in strata). The evidence to date suggests that human perturbation is considerable on a planetary scale.

The Anthropocene has, since it was first broadcast to the world by Paul Crutzen in the early part of this millenium, has become something of a phenomenon - a geological time term that is dissected and discussed by specialists in every discipline from archaeology to zoology: every intervening letter of the alphabet may, I am sure, be represented here (and if you think that 'x' seems a problem here, then I suspect someone, somewhere has already discussed it in a xenobiological context[1]). Why has the Anthropocene flown so high and so fast?

Part of the response to this new concept lies in the visceral reaction – almost a shock, perhaps – that fleeting humanity really can change the geology of an ancient planet, and re-direct the course of its history. Part may lie in finding a different and perhaps less baggage-laden setting to consider the genuine and seemingly intractable problem of global warming. And part lies in seeing how the familiar everyday environment around us suddenly appears alien (there! – we have that xenobiology already) when translated into its geological components. There are probably many ways in which one can turn this idea around in one's head and reflect upon it.

But hidden somewhere within these many-sided reflections is the analysis of the Anthropocene as geology – or, more precisely, as stratigraphy, the classification of the world's rock strata. And this business – especially, the formal business of subdividing the four-and-a-half-billion-year span of the Earth's history into units such as the Jurassic and Carboniferous and the Maastrichtian – has traditionally been the most obscure of studies, the preserve of dedicated and highly specialized geologists and palaeontologists. They work very slowly (over decades, usually), well out of the public eye: their concerns are highly technical and their carefully weighed determinations have only been of concern to other geologists. Until now, that is.

How then, can these worlds fit together? Well, with some difficulty. But one factor within the emergence of the Anthropocene that may be able to tell us something useful about the human phenomenon is the way that the science of stratigraphy has itself changed. It started, pretty much, as the science of the classification of strata, sometime in the sixteenth century, with such as Johann Gottlob Lehmann in Germany and Giovanni Arduino in Italy. They found it useful to classify rocks, as this made it far easier to predict what kind of resources - coal, gold, silver, tin – may be found in them and extracted from them.

---

[1] Alas, xenophobia may occasionally come into the debate, too.

This practical tradition in stratigraphy persists to the present day, though Lehmann's and Arduino's crude divisions have been divided and subdivided to an almost infinite degree. In Britain, the art of geological mapping arguably saw its apogee in the coalfields, repeatedly surveyed in ever more detail, showing the location of thin sandstones that one has to get down on hands and knees to see, and the places where coals not much more than a few centimetres thick come to the surface. Young geologists working the oilrigs today are working flat out, examining fossils just arrived in drilling mud at the wellsite, to 'biosteer' a drill-bit kilometres below the surface, so that oil can be sucked out from the thinnest ribbons of productive reservoir. It is this refinement of the geological timescale that allowed coal and oil to be brought out of the ground in huge amounts (over half a trillion tons, by now) to be converted into energy for us, and into carbon dioxide gas for the atmosphere.

But the intensely practical early geologists were curious, too. Lehmann saw that the shales above the coal seams contained the remains of plants that were clearly unlike the modern plants growing above the coal mines; he found amber too, and within it insects that he looked at closely enough to see that they were unlike the local insects of the day. These were very early days in the science but – even though he held to the then-dominant idea of the biblical Flood – he could see that the world had changed.

A little later – though still before the French Revolution - the great naturalist Buffon used the evidence of the rocks and the fossils to write, in *Les Époques de la Nature*, the first geological history of the Earth. He used the evidence of rocks, minerals and fossils to show that mountains had risen and been eroded, that sea level had changed, and that the different life-forms had come and gone. He tried to infer how these changes had taken place, too. It was hit and miss. Volcanoes, he opined, were driven by chemical reactions as seawater broke through into underground caverns. He was *mostly* wrong in that, but had extraordinarily accurate insights into the nature of buried coal seams: they were fossilized swamps, rather like those of present-day Guyana, he said.

From Lehmann and Buffon to today, the practical business of cataloguing and classifying the world's rock formations has intertwined with the study of the Earth's history and the mechanisms that have controlled its evolution, as gleaned pretty well solely from the evidence in the rocks (we have no other source). Both have been stunningly successful. On the practical side, the resources drawn from the Earth have built and powered an enormous civilization, including the reversal of several hundred million year's worth of transfer of carbon from atmosphere to bedrock. As regards scientific knowledge, we have built up a detailed history of the Earth that is fundamentally secure, if still incomplete in many aspects. We *know*, for instance, that a large meteorite impacted upon what is now the Yucatan Peninsula of Mexico, some 65 million years ago (give or take a million years); we can reasonably infer its size (about 10 kilometres diameter), its speed (about 10 to 20 kilometres/second) and aspects of its composition (iridium-rich). There is very good evidence that it precipitated a mass extinction on land and in the sea, but we have not yet established whether it was the sole factor causing this catastrophe (there were very large volcanic eruptions taking place at about the same time) or constrained the kill mechanisms in detail.

And so these studies have proceeded. Consideration of the geology has involved consideration of a world that for almost all of its history did not have humans. Our species has been in existence for much less than a million years, anything that we might call a civilization is just a few thousand years old, and the industry that now supports it is barely more than a couple of centuries old. Consideration of the dynamics of the human enterprise - economics, history, politics and so forth – has mostly treated the ancient Earth as a backcloth (all-providing, resilient and essentially stable) for our activities.

This has changed. Now, the history and activities of the human enterprise are recognized to be of a speed and a scale sufficient to change many fundamental geological processes of the Earth, and to change the trajectory of planetary history. We have to adjust to the idea that that specific human decisions and initiatives may have consequences that will be perceptible for millions of years, rather than just months and years, into the future. How though, may such consequences be assessed?

The basis of the Anthropocene rests upon comparing what we can see happening at the present day, and what we have recorded scientifically, since systematic recording began – really, only over the last century or so – with what we can infer, forensically, from the evidence preserved in rock strata. So, if there are phenomena that do not fossilize, then they cannot be used in analysis of the Anthropocene, because then all we have is modern experience, with no preserved context to place it within.

Some things do not fossilize at all in the natural world. The pattern of sound is one such thing, whether as spoken words, music or simply noises. Sedimentary strata simply do not encode this kind of information, with the possible exception of the fracture patterns left in rocks after earthquakes or meteorite impacts, which represent *extremely* low-fidelity auditory recordings. Human technology, from the days of Edison (and a few earlier pioneers) uniquely enabled this kind of fossilization, which is now commonplace as different kinds of sound recordings. But it has no counterpart in the four and half billion years of Earth history.

Other things can be recorded in strata, to a greater or lesser extent. For instance, one of the defining issues of our present time is the burning of fossil fuels for energy, and the consequent buildup of carbon dioxide in the atmosphere. We know empirically, from the experiments of John Tyndall in the late nineteenth century, that this gas, even in small quantities in the atmosphere, lets in incoming light but traps outgoing heat, and so its increase is a concern. But how can we evaluate the present-day trend? Only, of course, by going back to the past. And here the story is complicated.

Going back almost a million years - 870 000 years so far, to be precise - there is real fossilized air, preserved as bubbles in ice layers, representing compressed snow, within the Antarctica icecap. These can be analysed to allow the concentrations of carbon dioxide (and other greenhouse gases, such as methane) to be measured. It is an excellent and reliable record, having been replicated in different drilled-out ice cores obtained from Antarctica (and in Greenland, too, though the ice there is not so old, only going back about 130 000 years). This shows us clearly that levels of this gas have changed with almost metronomic regularity from about 180 (in cold glacial phases) to about 260-280 (in warm interglacial phases) parts per million over that time. Yet another indicator, the different proportions of 'heavy' and 'light' isotopes of oxygen and hydrogen in the water molecules of the ice, can be interpreted to indicate the temperature at the time the snow was falling – and so the link between climate and greenhouse gas composition can be made.

Continuous, contemporary scientific measurements of carbon dioxide in the air have only been made since 1958, largely due to the scientist Charles Keeling's legendary persistence in pursuing this topic (thought a chimaera by many of his colleagues). The resultant 'Keeling curve' when placed alongside the ice record, shows that the contemporary rise (from ca 315 ppm when Keeling started, to ca 400 ppm today) is without precedent in the last 870 000 years. It is a clear signature of the Anthropocene. But, how does it compare with carbon dioxide in yet earlier times?

This is more problematic, because, beyond the Antarctic ice record, which has almost, but perhaps not quite, been plumbed[2], it is much more difficult to find

---

[2] Scientists are hoping to extend the record back to a million years, but this won't be easy.

evidence of how much carbon dioxide was in the atmosphere in ancient geological times. It is not quite impossible, though, for some indications can remain in the strata. Very well-preserved fossil leaves, for instance, may preserve stomata – small holes in the cellular structure that allow gas exchange: the more holes, the less carbon dioxide, by and large. And with more carbon dioxide in the atmosphere the water becomes a little more acid, and this change in pH can be tracked, rather imprecisely, by chemical tracers in the rocks such as the amount of boron in the calcium carbonate shells of marine microfossils. A lot of effort has been spent in trying to refine these indicators, and the consensus is the last time that atmospheric levels of carbon dioxide were ~400 ppm was in the Pliocene epoch, some 3 to 5 million years ago – when the world was a couple of degrees warmer and sea levels some 10 to 20 metres higher than today (these last values being established by using other chemical characteristics of the strata).

Going farther back in time is yet more difficult (the chemistry is less well preserved, and the fossil leaves are no longer very similar to modern leaves). Nevertheless, current assessments suggest that, if current trends persist, we may reach the 'hothouse' levels of about 800 ppm, of more than 35 million years ago, by the end of this century. It is a measure of how rapid, and how large, today's change is.

And so the comparisons go on. In trying to compare the present and the past biosphere, we mostly have to look at animals and plants that have fossilisable hard parts, such as mammals and molluscs: it is much harder to assess what is happening with jellyfish and with sea anemones in a deep time context. The evidence from the sea (where strata is easily preserved) is better than that from the land (where it is easily eroded).

It is rather laborious work – but it does show us, quite clearly, those aspects in which the Anthropocene is a strikingly distinctive geological phenomenon, and those in which it is minor. The results are sometimes surprising. So as regards climate change per se, and particularly global average temperature, we are still firmly within standard interglacial norms. Even despite the temperature rise of the past century, of just under one degree centigrade (almost certainly largely human-forced), there still needs to be about a further one-degree rise to take us to the peak temperatures of the last interglacial phase, about 125 000 years ago.

This is even more the case with sea level, which has gone up by about 30 centimetres in the last century – a geologically trivial amount. Again, sea level in the last interglacial peaked at about 5 metres higher than present-day levels, without any human encouragement whatsoever, and at carbon dioxide and methane concentrations (that we know well, from those ice cores) similar to those of the Holocene in pre-industrial times.

That seems to suggest that global temperature and sea level are sensitive to small changes in the governing parameters. With the drivers of climate warming now greatly intensified (and intensifying year by year), we are storing up rises in temperature and sea level that will take us, over decades, centuries and millennia (the Earth is a very large object, and will for some time store much of the extra heat in oceans and rock masses), into a world outside the envelope not just of Holocene conditions, but of those of the whole Quaternary Period in general. But, we are not there yet.

Other geological changes in the Anthropocene are much further advanced. The translocation of thousands of species, wittingly or unwittingly, between every continent and every ocean. The reshaping of landscape by agriculture and urbanization, and of the geography of the sea floor (on the continental shelves and the upper parts of continental slopes) by deep trawling. The production of many millions of different types of technology-produced objects - that one might interpret as 'technofossils', as many are perfectly fossilisable. And there are hidden changes too, with few obvious direct environmental effects (there are many indirect ones): our burrowing as ‘anthroturbation’, kilometres into the ground, in mines and boreholes.

It is a kaleidoscope of changes, some that will stop forming if we were to disappear (the roads and buildings of our ‘urban strata’) to others whose effects will last for tens to hundreds of thousands of years (the perturbations to the great chemical cycles of carbon, nitrogen and others) to others that are already effectively permanent (the biological changes).

The Anthropocene – whether formal or informal – clearly has value in giving us a perspective, against the very largest canvas, of the scale and the nature of the human enterprise, and of how it intersects (‘intertwines’ now, may be a better word) with the other processes of the Earth system. It hence may be useful – but may be in danger of being over-interpreted - in political and social debate. In the end, though, it is a story, a rather remarkable one, of Earth history. Whatever moral might be drawn from it depends closely on what we can interpret of the preceding four and a half billion-year story of this planet. Context is everything.