GEOBROWSER

How we got our oxygen

The focus today seems to be mainly on global climate change, particularly the link between warming of the planet and the exponential increase of atmospheric CO_2 since the start of the Industrial Revolution. But in the long run oxygen is far more important because without it animals, and therefore us, would never have evolved in the first place. A number of studies are now linking the oxygenation of our atmosphere into a complex, long-drawn-out scenario involving plate tectonics, biological evolution and chemical reactions.

Most workers agree that by the end of the Hadean Period of meteorite bombardment about 3800 million years ago, the earliest atmosphere essentially consisted of hydrogen and oxygen – in other words water vapour. Much of this fell out as rain, and virtually the whole of the Earth's surface was covered by ocean. In these waters the first life-forms evolved as anaerobic bacteria. They did not need free oxygen, but with the sun significantly cooler than it is today they played a role in keeping the planet warm by releasing methane to the atmosphere (*Science, 2002, p.1066*). In this inviting situation, the cyanobacteria began to develop. The best-known are those that form stromatolites, living today but found in rocks dated to 3500 million years old *(Nature 2006, p.714)*; the super-abundant modern microscopic organism *Prochlorococcus* has also been identified as a living ancestor of the cyanobacterium (*Nature, 2003, p.1042*). The importance of these organisms is that they photosynthesize, releasing oxygen as a waste product to the local environment. But because early oceanic waters were rich in iron, there being no oxygen to combine with elements weathered from the adjacent landmasses, all of this released oxygen was initially combined into the iron oxides magnetite and haematite; this chemical process peaked at around 2500 Ma, when particularly voluminous banded iron formations were laid down.

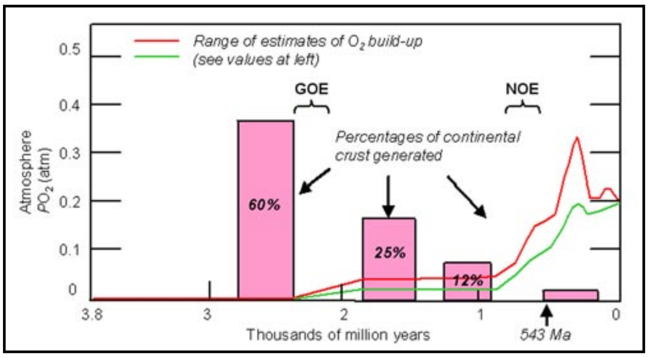
Stromatolites alive in Shark Bay, Western Australia.

Banded ironstone formation from Australia.

Plate-tectonic driver for the planet's oxygenation

Most of the major banded iron formations we see today immediately pre-date the first Great Oxygenation Event (GOE), which occurred between 2450 and 2200 Ma ago. This event is commonly attributed to the new availability in the atmosphere of photosynthetic oxygen (*Nature, 2004, p.913*); however, there was another factor, less obvious but equally important. Large tracts of shallow shelf seas were now in existence and they trapped sediment, including reduced organic carbon, thus preventing the capture of free oxygen from the water (*Nature, 2004, p. 913*). Secondly, they provided lagoonal environments for the type of cyanobacteria that make up modern stromatolites.

To form shallow seas requires the growth of landmasses and therefore of continental crust, which means that plate tectonics, rather than simple biological evolution, could be regarded as the principal underlying force driving oxygenation. This is the concept behind the theory of a Cybertectonic Earth (*J. Geol. Soc., 2007, p.*277); to some extent it opposes Lovelock's Gaia Theory (*Oxford University Press, 1979*), in which the importance of the biosphere tends to be unduly emphasized in the context of overall planetary evolution. As the graph shows, crustal growth has occurred incrementally (*J. Geol. Soc., 2010, p.229*) with the most productive phase, involving the generation of 60% of the planet's continental crust, pre-dating and thus possibly acting as one of the triggers for the Great Oxygenation Event. Following this, oxygen build-up

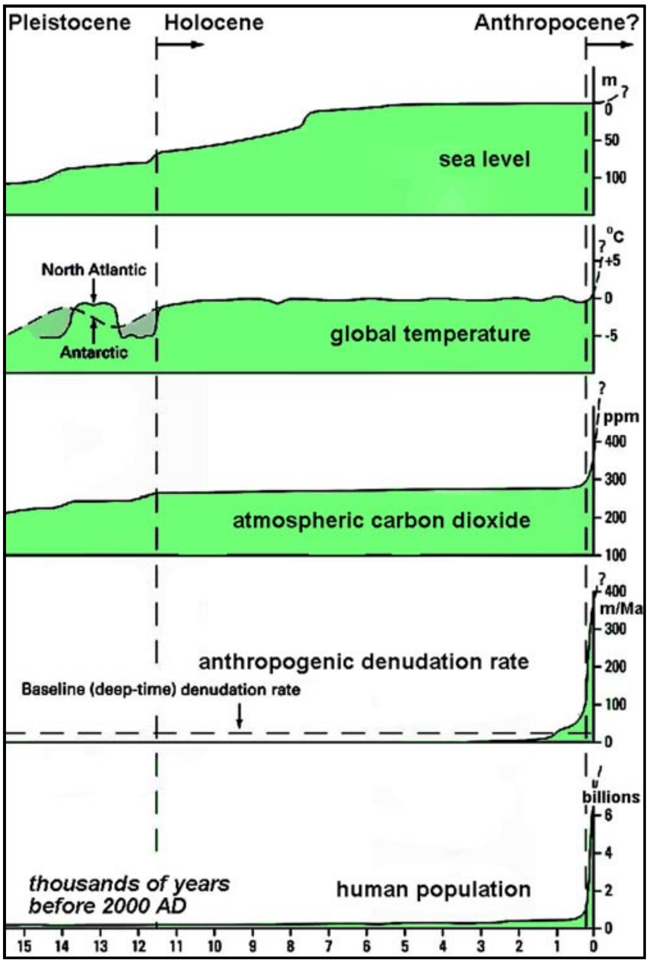


Oxygen levels correlated with continental growth.

levelled out in response to its involvement in weathering processes on the new landmasses, as well as in formation of the ozone layer. By Neoproterozoic times (600 Ma) however, these 'sinks' (to which oxygen was lost) had been largely filled and atmospheric oxygenation proceeded apace, resulting in the Neoproterozoic Oxygenation Event (NOE) (*Geol. Soc. Amer. Today, 2011, p.4*). This paved the way for the rise of animals in the final part of the Precambrian, and the explosive increase of animal life after this period had ended, 543 million years ago.

Anthropocene: a new geological epoch?

In 2000 Paul Crutzen, a Nobel-prize-winning chemist, made an off-the-cuff remark that the Holocene Epoch (the latest division of the Quaternary Period) had ended – to be replaced by the Anthropocene, in which the global environment has been changed by the effects of human development. The suggestion was taken seriously by others, and a recent publication by the Stratigraphy Commission of the Geological Society of London has discussed these effects in an attempt to ask whether such a new term can be justified by formal recognition, and if so, where and how its boundary might be placed.

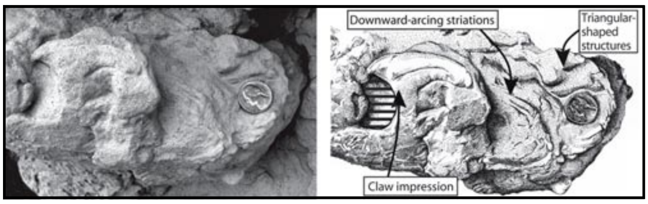


Parameters that may relate to the Anthropocene.

As yet there is no precise starting date for the Anthropocene, and until this is decided it must still be regarded as an informal term, albeit with an ever-increasing degree of usage. Certainly one could employ a number of criteria to measure and/or observe the first impacts of human development. Some suggest going back as far as 8000 years ago, when ancient farmers began to clear forests to grow crops *(Nature News, 10th December 2003*), but as the graph shows many of the more distinctive patterns we associate with human interference (e.g. atmospheric CO_2, anthropogenic denudation) would not have existed then. In a conference on the Anthropocene held at the Geological Society in London in May this year, others argued that 8000 years ago only one fifth of the planet's ice-free surface had been modified, whereas by 1750 AD not only was the Industrial Revolution starting but half of the Earth's biosphere qualified as being semi-natural and 'used'. The Stratigraphy Commission concluded that it may not be possible to set a date for the Anthropocene that would satisfy every criteria of human impact, but that a best guess around 1800 AD could be practical enough.

Digging for food: cunning dinosaurs

Perceived wisdom has it that large, lumbering dinosaurs rather stupidly laid their eggs in nests that could easily be robbed by nimble, quick-witted early mammals. With this type of scavenging, and then the meteorite impacts (*Geobrowsers passim)*, no wonder they were doomed to eventual extinction. However, features found in Late Cretaceous strata in Utah, USA, suggest that this was not always the case; before the K/T boundary extinction, dinosaurs were beginning to turn the tables on the mammals (*Geology, 2010, p.699*). In a sequence of overbank sandstones representing part of a fluvial floodplain, remarkable mega-trace fossils have been found, and interpreted as complex burrows. They commonly end in small chambers that the study compares with those made by modern rodents; but associated with the burrows are scratches and claw marks with a scale and morphology typical of a predatory dinosaur, probably a maniraptoran theropod. This study is the first to uncover dinosaur *strategies* for hunting burrowing mammals, as opposed to previous evidence of dinosaur predation such as bite marks, gut contents, coprolites and trackways.



Dinosaur trace fossil from Utah.