The Emerald Planet

How Plants Changed Earth's History

D.Beerling

November 18-21, 2010

Earth has a history. On the most basic level a geological history, where the processes are generally slow and work over long time intervals, measured in mega years. There are of course some exceptions, such as volcanic eruptions and earth quakes, but even those, in order to have sustainable effects, most extend over time. Other bodies in the Solar System also have geological histories, of which we know very little. Something catastrophic must have happened to Venus, and Mars does show tantalizing traces of a different era with more abundant flowing surface water. Many of the Moons of Jupiter are still very active geologically, while our Moon seems a dead body by any count. But Earth has also a history of life, which is far more diversified and interesting, than any geological story. This is also a slow moving history, at least by human standards, yet quicker and more versatile than the glacial progress of mere geology. In many ways the history of life rides on the history of geology which provides the context in which it develops. The conditions for life has varied greatly, but not catastrophically, in the last two or three billions of years. The thesis of the book is that this has not entirely been a one-way street, life itself has in crucial way altered its environment. This is of course true on the most recent layer of history, that of man and civilization, in which we count in years, in fact sometimes in far shorter time-bits when an actual crisis is unfolding. Mans impact on the environment has been far reaching as it has essentially colonized every nook of the surface of the Earth, the depths of the Oceans excluded. Of course by relating the larger time-scales to that of recent human history, the book achieves a topicality which I think is not essential to its message, by relating to the the present Global Warming. Obviously publishers may have put some pressure in this regard.

Scientists of today do not write as well as they did in the past. One may speculate as to why. Maybe because of increased specialization, the loss of the tradition of engaging with the imagination of an intelligent lay-audience and the subsequent reliance on technical jargon. Obviously the author seems somewhat unsure of himself, not to say out of his depth. There is no clear narrative, unwarranted digressions (such as the one on Senior Wranglers in Mathematics during the 19th century), unnecessary repetitions, embarrassing hyperbole, and most irksome of all, a reliance on hackneyed phrases and cliches. What about editorial help? Some of it must have been forthcoming, gentle advice, insistent advice, desperate advice, the outcome of which may have been not much more than uneasy compromise[1]. This is a pity, because the story to be told is of course compellingly interesting.

Now, the approach of the author should be commended on its focusing on method-

[1] In fact one does not discern in the text the voice of a single author, but rather one gets the impression of there being at least two.

ology, rather than resorting to mere description. Paleontology, paraphrasing the British historian R.G.Collingwood, is about reconstructing the past in the present using available documents and methods. Thus the findings of science are at best provisional, and hence liable to be modified in the future. This does not mean that they are mere phantasies, or in the terminology of modish post-modernists skepticism, mere social constructs, although the scientific project is an intensely social one, depending on the disinterested cooperation of the many. Hopefully we may see the accumulation of scientific knowledge as asymptotically converging to Truth with a capital 'T'.

Any historical inquiry is about interpreting the traces the past has left in the present. To do so is never easy. Still there is an asymmetry between predicting the future and divining the past, although on very basic physical levels, there seems to be no difference at all. In short the basic laws of mechanics know no arrow of time. The main difference is that the past leaves documents, the future does not. Thus the elucidation of the past is a forensic inquiry, requiring the approach of a detective. Detective stories turn out to be popular among the public, the reason being, it is not too far-fetched to assume, that the reader is intrigued by puzzling data and craves to find a coherent explanation of them, putting them into a place in a logically coherent framework. The latter providing the long awaited release to tap the accumulated suspense built up by sustained stimulation. Now commendable as the ambition is, it is not so easy to implement. There is a danger that the narrative becomes too confusing, when various conjectures are presented, buttressed only to be rejected. The reader is tossed up and down and may in the end retain very little from this confusing mosaic of conflicting theories and evidence. Unfortunately I cannot say that the present book has been able to sidestep such obvious pitfalls. Now the ultimate test of a book is what it has purveyed to the reader. What has it purveyed to me?

At the outset the book takes issue with the popular Gaia hypothesis that the Earth atmosphere is a self-regulating system geared to provide the optimum for life, in particularly that it is stable. According to its main proponent - James Lovelock, the fraction of oxygen in the atmosphere has always been around 21 percent at least since the emergence of life or its 'higher forms'. If the oxygen level rises too much, forests will burst into flames, and as a result consume a lot of oxygen. This is not true, the oxygen level of the atmosphere has varied widely, sometimes been as high as 35% some 300 million years ago during the Carboniferous period, with a subsequent crest during the end of the Cretaceous period. While at other times it was as low as 15%. In fact from more than 500 million years ago and during a 'brief' dip 200 million years ago. This of course has had major impacts on the flora and fauna. When the atmosphere is rich in oxygen, giant insects such as the dragonfly can flourish, something which would be impossible today in a less dense atmosphere[2]. Now two basic questions impose themselves. The first is how do we know? How can we find out the oxygen level so far back in time? The second is to explain how it came about.

[2] Higher density of the air would of course make flying easier, if slower, due to increased friction and hence lift. Still the atom weight of Oxygen being 16 as opposed to 14 for Nitrogen, makes for a rather marginal increase in air density In fact about 2%, a similar change is affected by a rather modest change in altitude of about 200 meters. In fact the increased density of the air would have had no essential effect on the growth of such mega-insects. More important would be the metabolic rate effected by a higher oxygen content.

The first has a very complicated answer, the second a deceptively simple one. The first is known as hard science, involving a lot of communal effort and resources and builds on ingenuous ideas of very many people, and would be very hard to convey in all its technical subtleties to a general public. In fact even to a scientist, a supposed expert. The second builds on a clever idea hatched by a single mind, and easily conveyed and grasped. So let us start with the last. Plants processes carbon-dioxide through photosynthesis producing oxygen and building themselves up by carbon. This clearly increases oxygen and decreases carbon-dioxide. In the end there would be no carbon-dioxide in the atmosphere to process, and plant growth would come to a stop, unless there would be an external supply, such as volcanic activity. However, plants decompose and in the process they consume oxygen and release carbon-dioxide. We have a recycling process, which in principle could go on for ever. But if there is no perfect match, say if the decomposition of growth does not keep up with the production, the net effect would be an increase of oxygen in proportion to the discrepancy. If the discrepancy is very low, the build-up would be very slow, but of course there is no shortage of time in geology, and small effects over long stretches of time have spectacular effects. This is indeed one of the major insights proposed by Hutton at the end of the 18th century and Lyell in the 19th century, namely the principles of uniformitarianism, providing the major methodology. It means that the workings of geology are to be observed in the present, that nothing catastrophic nor miraculous need to be invoked. The present is the key to the past, it is just a matter of scaling well known processes. Now the difficulty with such simple explanations is that indeed they are simple. One has to take into account other scenarios, that may contradict or at least work counter to the cherished one. One has to take them all into account and weigh them appropriately according to quantitative considerations. Some effects are so small that they are drowned in the general picture[3]. It is here mathematical modeling comes in. Mathematical modeling is not only about crunching numbers, although that is undeniably important, it is also a matter of realistically model actual phenomena. Without a realistic model the data it will spit out will at best be irrelevant, most likely misleading. We have here touched upon one of the key ideas of mathematical modeling in geology and climate studies (the latter can be seen as the 'geology' of the atmosphere), namely various feed-back mechanisms. Some of them are reinforcing, vicious circles, and would in principle spiral out of hand, unless being stymied by other processes. As we say no tree reaches the sky. Others have negative feedback, and hence tend to stabilize. Others still relate states not just to the change but the change of the change, and gives rise to periodic phenomena. Cycles in fact that merely rotate around an equilibrium. The mathematical ideas involved are fairly simple and straightforward. The complexity is not conceptual, but due to tinkering with the models in order to get a better and better fit. The actual calculations can be formidable indeed, and the detailed use of mathematical simulation has only come into the fore with the recent advent of super-computers. In fact they have become so crucial as almost be seen as part of the empirical research.

How to measure the actual oxygen in an old atmosphere is a formidable challenge. To actually directly measure it, as we can with air trapped in old ice, only works for a million years back. And even that, conceptually simple, is technically rather difficult

[3] The previous footnote is an illustration of that.

involving a lot of resources, human, technical[4], and is only done if a very good case can be made for it. To go back further in time far more indirect method must be used[5]. Those depend on provisionally accepted theories. In Science, unlike mathematics, long chains of reasoning tend to be very speculative, as uncertainty is multiplied by each step. The key to robustness is independent corroboration, which makes every statement dependent upon a reinforcing network of supporting facts and reasoning. Few if any people may have complete overview of this. Science is a collective enterprise and hence also a pragmatic one. As long as things work, there is no need not to accept it provisionally. Only by exploring its ramifications, forward reasoning, or ablative logic in the words of C.S.Peirce, may we test its soundness. I have to admit that I did not get a very compelling explanation how the indirect estimations are made. But this was not the object of the author, who wanted to proceed from the fact of vigorous oxygen fluctuation to proceed and discuss its ramifications, rather than get bogged down in technical detail. This illustrates that the commendable approach of focusing on methodology and the interpretation of its results, can hardly be exploited systematically. As we say in mathematics, a certain amount of hand-waving has to be done. This does not of course in principle invalidate the approach.

Now the book discusses in the above vein a number of topics. One is the presence of mass-extinctions as evident from the fossil record. Now, as Darwin famously pointed out, the fossil record is patchy and random, and lacunae may not have any real existence, so mass-extinctions can only be inferred from an overwhelming indication. Another thing is to explain them. Nowadays everyone is aware of the impact theory concerning the most recent 65 million years ago. There is a lot of evidence for it having accumulated since the physicist Alvarez originally proposed it thirty years ago. There is hence a natural tendency to explain the others in a similar vain[6], but those could as well been due to catastrophic developments of the atmosphere. However, the crucial emphasis is on plants. They make up the higher amount of biomass, and also the photosynthetical process is a major industry on Earth, the consequences of which, we have already remarked, may over time be crucial. One problem addressed is why the evolution of leaves was so delayed? Once again the spotty record may obscure the picture, and there is always the chance that future finds will make us reevaluate our conclusions. More interesting though is the development of a new kind of photosynthesis which is more effective than the old one. It is referred to as the C_4 method as opposed to the old C_3. In times of low carbon-dioxide level, it may give a crucial edge. Trees and other leafy plants are of the old kind, while grasses and many of its relations, are of the newer kind. There is actually a kind of warfare going on between C_4 and C_3. Forested areas have been replaced by Savannahs, and the way it has been done is through forest fires. Grasses are more likely to reclaim a devastated area than trees, and they also in a sense make forest-fires more likely by producing a drier climate and providing more combustible fuel. This has been going on in the last eight million years.

[4] Such as drilling very deep holes indeed and retrieve usable ice-cores to be studied with a minimum of outside pollution skewing the measurements beyond the useful.

[5] A standard method in geology is statistical isotope measurements.

[6] I recall a fancy theory postulating a dark companion star to the sun, actually christened to Nemesis, which would be responsible for a periodic increase in comets and small asteroids intersecting the earths orbit around the sun.

It has also led to cooling, as the light expanses of Savannahs have higher albedos than forests, thus capturing less of the solar energy.

Finally at some length the warm period of the Ecocene is being addressed. During this time, as in previous eras of Dinosaurs, there were no polar ice, and conditions around the poles were balmy. How did this come about? Substantially higher CO_2 levels, actually six times those of the present, cannot be the whole story. There are other green-house gases, methane being a well-known example, which actually are far more effective, molecule for molecule, than CO_2[7]. There is also a discussion about what kind of trees those arctic forests would consist in, being swamped in darkness for significant periods of the year. The original idea that they most all be deciduous, because shedding leaves would be less costly than trying to keep needles alive, has been jettisoned when the cost-benefits have been investigated more closely using controlled experiments[8].

In conclusion, pace the assertions of the author, past climate changes probably have little relevance to the problems we face today, except from the general insight that even small changes can have momentous consequences. We may learn from history, including geological history, but the lessons we learn are never about specifics which me may apply today. Times do indeed change contexts.

November 21, 2010

[7] The author speculates whether it would not be more feasible to limit those gases in the atmosphere than the far more intractable CO_2 which is so essential to industrial growth and our modern society.

[8] An obvious line of inquiry one would think. Much of the present is actually a key to the past as we have noted above.