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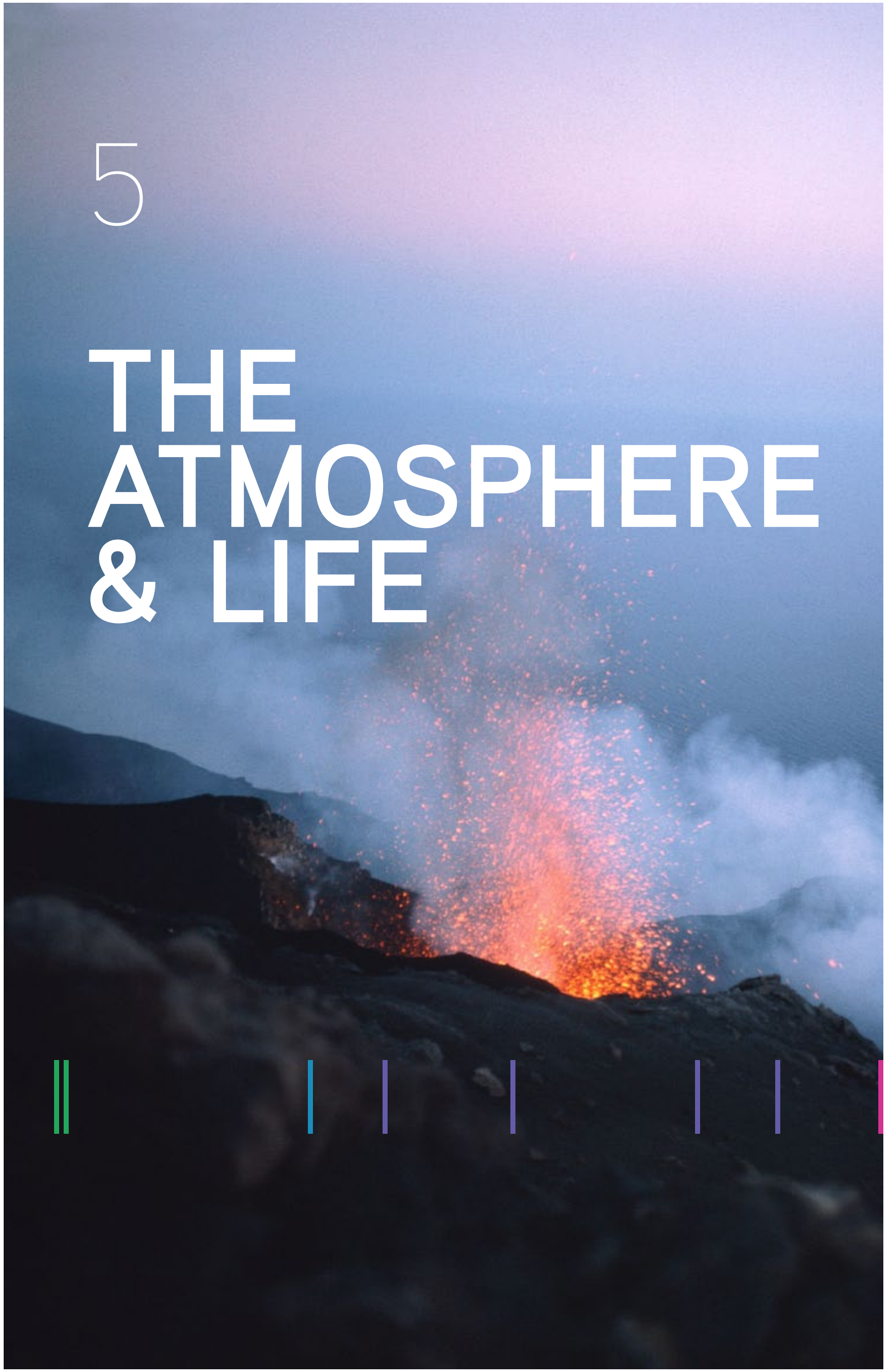
THE ATMOSPHERE & LIFE



BIG HISTORY PROJECT

THE ATMOSPHERE & LIFE

TWO ATMOSPERIC SCIENTISTS DISCUSS THE RELATIONSHIP BETWEEN THE ATMOSPHERE AND LIFE ON EARTH

A dialogue between David Catling and John Wallace

Geologic events and changes in the atmosphere play a critical role in shaping the biosphere. There is a complex balance between Earth's processes and its network of life.

The end of the “boring billion”

A fairly stable time in Earth’s history is followed by changes to the atmosphere and the biosphere.

DC: After the “Boring Billion,” a period about 800 million years ago, the Earth’s climate was fairly warm and stable. Life was fairly simple and the surface of the Earth had become oxygenated but there was still only a smidgen of oxygen compared to what we have today.

It would have been somewhere between 0.2 percent and 2 percent, while today we have 21 percent. So there wasn’t a lot of oxygen around in the atmosphere.

But the deep ocean was even less oxygenated. Some coastal regions were rich in sulfur, the kind that smells of rotten eggs called hydrogen sulfide. So, quite nasty smelly conditions for us and a place where animals still couldn’t live, but okay for some other kinds of life.

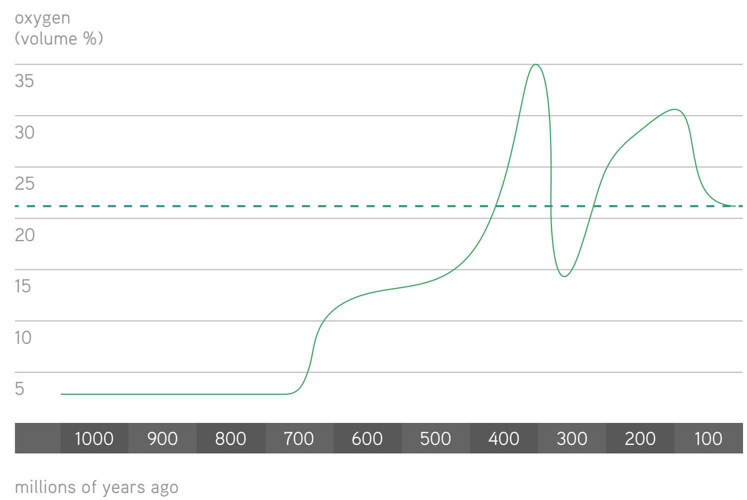
JW: Maybe some of those old timers from the previous age.

DC: [*chuckle*] Yeah, some of those old timers. If you didn’t use oxygen, actually it would have been a good place for them to hang out. Some organisms find oxygen quite toxic and they would have been fine before the rise of oxygen, but they would have had to hide away afterwards. In fact, they did hide away. They hid in the smelly muds of the deep sea and those kinds of places.

So the Boring Billion goes by in the Proterozoic Eon and there’s still no life that’s very sophisticated. There are algae and that’s about it. Maybe there are amoebae and things like that that are our ancestors ultimately, but still no animals. Then what happens is there’s a second rise of oxygen at the end the Proterozoic. What we actually think happened is that methane hadn’t quite gone away. These poorly oxygenated areas of the ocean that existed during the Boring Billion were actually big sources of methane because methane is produced by organisms that like to live

OXYGEN CONTENT OF EARTH’S ATMOSPHERE

During the last billion years



in these nasty muds. So there was a much bigger source, a bit like the sources of methane in the Black Sea today. The Black Sea is an area of the Earth that’s an inland body of water.

JW: Fresh water.

DC: Fresh…there’s a lot of fresh water, but it is connected to the Mediterranean which is connected to the Atlantic. In the Black Sea it’s kind of zoned. So the top of it is oxygen-rich, but as you go down it’s very oxygen-poor, and in fact, sulfur-rich. It’s a small area on the Earth today, but imagine that the whole ocean is a bit like the Black Sea. So it’s oxygen- rich near the surface and then very oxygen-poor, particularly on the slopes…the continental slopes. Those areas would be poorly oxygenated and big sources of methane.

Today, there's only 1.8 parts per million of methane in the atmosphere. So, of a million molecules, roughly two of them are methane. Back in the Archean Eon, before the rise of oxygen, it would have been thousands of parts per million. Then in the Proterozoic we think…certainly tens, but maybe 100 parts per million of methane. So it's still an important greenhouse gas.

JW: And not enough oxygen to support more sophisticated life.

DC: Yeah. And then oxygen rises a second time. We're not quite sure why. It's a bit of a mystery. And we see Snowball Earth glaciations occur again.

JW: Again, right…as a result of the rise of oxygen.

DC: That's what we think. The oxygen rose again and now it finally got rid of methane…scrubbed the methane out of the atmosphere. Methane went down to something more like modern levels of just being a very minor trace gas.

So we see these glaciations around the world, Snowball Earths. One is about 720 million years ago, roughly. We don't know exactly when it started and exactly when it finished, but we do know that in these rocks that were dragged along and eventually deposited by the glaciers, there's some volcanic ash that we can date quite nicely. The volcanoes spewed out some ash and it deposited. That's about 720 million years ago. Then the next one is something like 635 million years ago where we can find the volcanic ash in the glacial sediments again.

And there's a minor one, a little glaciation which we don't think was a Snowball Earth, about 580 million years ago. After, sometime between 630 and 580 million years ago, there's the very first signs of animals. Some look to be like sponges. There are also some molecules that were left behind; some organic molecules. We think, again, that the increase of oxygen would of at least been a precursor to allowing more complex forms of life to arise.

So the overall story here is that the evolution of the biosphere (the network of life on Earth) and the evolution of the atmosphere were linked. It was biology that changed the atmosphere, but then the atmospheric change, changed biology. So we couldn't have had the oxygen-rich atmosphere without the photosynthetic bacteria in the very early oceans, but we couldn't have had the animals without the oxygen coming in. There was an interplay between what the biosphere was doing and what the Earth was doing that included geologic events like volcanoes, organic processes like photosynthesis, and changes in the atmosphere.

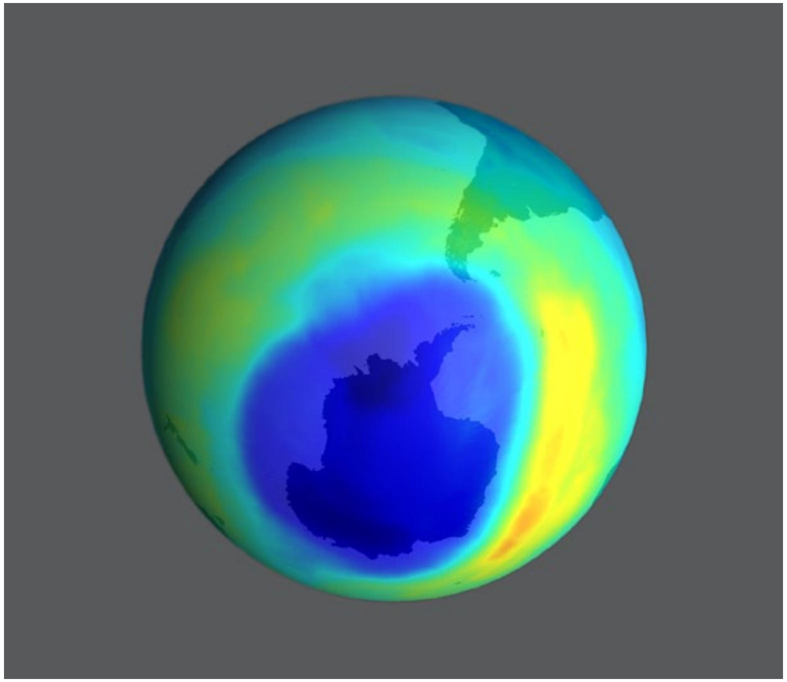
The role of the ozone

DC: Then the atmosphere, particularly the levels of oxygen combined with the climate, sets limits on what's possible for a biosphere. For life, we definitely need liquid water. Well, fortunately that was around very early as far as we can tell. Then we don't need oxygen just for very simple forms of life, but we do need it for the multicellular animals — the things that run around and eventually jump and eventually become intelligent.

JW: Because they consume it, but what about the ozone layer? Is that affected too?

DC: Oh, yeah. So one of the reasons the Boring Billion was not quite so boring was because we did get more diverse forms of algae, and during this time there was an ozone layer. So after the first rise of oxygen 2.4 billion years ago — even that little bit of oxygen that was around, somewhere between 0.2 and 2 percent, that was actually enough to make a fairly decent ozone layer.

So the ozone layer is a layer in the stratosphere; a layer enriched in the molecule which we call ozone which is O_3 — three oxygen atoms joined together. The height where there is the biggest concentration of ozone is about 25 kilometers above the modern Earth. So what happens is an



The Earth's protective ozone layer has an increasingly large hole over Antarctica

oxygen molecule (O_2) gets zapped by ultraviolent sunlight and it breaks apart and makes two oxygen atoms. But one oxygen atom then can combine with an O_2 molecule and it can make an O_3. So the abundance of O_3 molecules — the ozone molecules — ultimately are connected to how much oxygen is available in the atmosphere.

In the early days of Earth there was no oxygen worth speaking of, and there was no ozone layer. So it would have been nasty on the surface of the Earth because you would have been zapped by this very high ultraviolet energy that today we're protected from. That protective layer actually came in with the first rise of oxygen. It wasn't quite as thick as it is today because there still wasn't a lot of oxygen, but it would have been pretty protective of most of the surface of the Earth and it may have been enough to actually allow some diverse forms of life, even in the Boring Billion.

JW: You mentioned that as an ice age develops the ocean starts to freeze over first near the poles and then eventually just closing up entirely as the reflected light from the ice makes the Earth still colder and then makes more ice until the Earth becomes ice covered.

DC: Right.

The role of volcanos

JW: But you might think that once the Earth was ice covered and so white, and absorbing so little of the Sun's radiation, how could it ever get out of that state?

DC: Right. Well, this actually was a problem. There was a Russian scientist called Budyko who did some very simple climate calculations at the end of the 1960s — this is back when people were using pen and paper, not computers, to model a climate system. He realized that that was a possible state that you could get into for the Earth, just a reflective kind of ball bearing. He couldn't actually work out how it could get out of that state. Then in the 1990s, a scientist, Joe Kirschvink, who works at the California Institute of Technology and actually coined the phrase "Snowball Earth," worked with this idea further. He saw a way to get out of an increasingly colder, ice-covered Earth.

There are volcanoes on the Earth and they don't care about this ice sheet, right? They still go on and on pumping out their carbon dioxide gases and they'll poke through any ice sheet because they're hot. So if the ocean is isolated and the land mass is covered with ice, then there's nothing really to take up this carbon dioxide. Normally it would dissolve in rain water and it would react with the surface and be diminished, but in the absence of rain and the absence of the ocean being in intimate contact with the atmosphere, the carbon dioxide builds up. It's a greenhouse gas and eventually it reaches a threshold and then it will melt back the ice sheet.

When this happens, the snowball effect goes into reverse. As the ice sheet melts back it becomes less and less reflective, which means it becomes warmer and warmer and warmer, and then the ice sheet retreats entirely. In fact, people suggest that what happened after the Snowball Earth is actually a very hot period because, when the ice goes away, suddenly you're left with all this carbon dioxide.

Within several tens of thousands of years it will go away and disappear, but it initially would have been a hot house. So you go from a glacial period to a hot house. In fact, what may have happened to make these multiple glaciations — certainly in the very early period — is that there was still some instability in the composition of the atmosphere. The change from glaciation to hot house would have messed around with the biosphere and its output of gases, so this could have meant that with the first rise of oxygen that you didn't actually get to the stable oxygen-rich state. You may have gone back into a poorly oxidized state of the atmosphere. You may have had to go through the rise of oxygen again with another glaciation until eventually you settled down over a few hundred million years.

But we're still working on that. There's still a lot of uncertainty because it's like a detective story where you have little bits of evidence and you have to piece them together to make sense of everything.

JW: One kind of left over question that comes to mind is….You've seen how much of today's atmosphere, the basic elements of it, came out of the Earth in volcanic eruptions.

DC: Right.

JW: And we still have volcanic eruptions today — like we had a big eruption in the early 1990s — Mount Pinatubo. Did the carbon dioxide concentration in the atmosphere or the water vapor in the atmosphere increase dramatically after that? Can we see any evidence of that?

DC: Well, of the volcanoes that go off today, individually the amount of carbon dioxide they put out into the atmosphere is still quite small compared to the carbon dioxide in the atmosphere as a whole. So the way they tend to affect climate actually is to cool the climate. The way they do that is because they also put out a lot of sulfur gases and some of them are the types of volcanoes where the sulfur gets up into the stratosphere and it reacts with water vapor. And there are tiny sulfuric acid particles and they're very reflective. So they reflect the sunlight and they can actually cool the planet for maybe a year or two until eventually they disappear. They fall out of the stratosphere.

When we look at the global climate after Pinatubo, we see that the climate cools for a little bit, for a year or two after that volcanic eruption. But the amount of carbon dioxide coming out of the volcanoes, all of them together, today is dwarfed by the amount that is being released from burning fossil fuels…You can think of the humans burning the fossil fuels as being this sort of giant volcano that produces a hundred times more carbon dioxide than the volcanoes.

The 1991 eruption of Mount Pinatubo in the Philippines affected the global climate

So what happens in the absence of humans is that there's a little…there's a very slow loss of the carbon dioxide by dissolving in rain water, reacting with rocks on the continents, and then being washed into the rivers, and then being lost. That gets replenished with the carbon dioxide that comes out of volcanos. If there's a particularly strong episode of a several hundred years or thousands of years of volcanism then the carbon dioxide will go up a bit, but —

JW: Very small compared to what we're doing.

DC: Very small compared to what humans are doing because humans are quickly extracting the fossil fuels out of the ground and they're burning them extremely rapidly, especially when you consider the vast geological time scales that produced these materials.

David Catling

David Catling (DC) is an associate professor in Earth and Space Sciences at the University of Washington. He focuses on the evolution of the Earth's atmosphere and the evolution of other planetary atmospheres with an emphasis on Mars, as part of NASA missions. He also examines the origin and evolution of life on Earth, with an eye toward the potential of life elsewhere.

John Wallace

John Wallace (JW) is a professor of Atmospheric Sciences at the University of Washington and the former director of the Joint Institute for the Study of the Atmosphere and Ocean. His research focuses on global climate, covering topics like El Niño and global warming. He is co-author of the standard introductory textbook to the field: *Atmospheric Science: An Introductory Survey.*

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