The formation of oxygen in the Earth's atmosphere

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When we look at other planets and ponder the possibility about there being life on these other worlds we tend to compare them with the Earth as it is today. And we know that our life depends on the oxygen in the atmosphere. Yet the Earth was not always like this, and, in fact, if the Earth had always had free oxygen in the atmosphere life might never have formed on our planet.

When the Earth formed about 4 600 million years ago there was no free oxygen in the atmosphere. Geologists suggest that the only free gases that existed at that time were hydrogen, carbon dioxide, and nitrogen.

The Earth was mostly covered with a layer of water, with perhaps a small, low-land area sticking up out of the sea. The continents that gradually emerged from this sea were totally barren. As there was no oxygen in the atmosphere there was also no ozone to filter out the Sun's UV radiation and so the temperature on the Earth may have been as much as 85°C. Days were somewhat shorter than they are now (the Earth is slowing down at a rate, now, of 1.4 ms per century) and the Moon was a lot closer to the Earth causing massive tidal action. (The Moon is currently receding from the Earth at 2–3 cm per year.) The land masses were totally barren, maybe resembling the surface of Mars as we see it in photographs. There were many active volcanoes spewing all sorts of things into the atmosphere and probably also a lot of comets and asteroids slamming into the Earth. It has been suggested that there may have been as many as 10 000 comets that collided with the Earth before 3500 million years ago.

To form a simple living cell you need some 24 amino acids. The term 'amino acid' is just a posh way of labelling complicated molecules that you can't easily find a name for – just strings of hydrogen, nitrogen, carbon, oxygen and some other elements in small quantities. Just the sorts of things that were around in abundance in the oceans and

Table 1. The Geologic Time Scale

10^6 yr	Time	Era	Period	Epoch	Comments
4600		Archean			Formation of Earth
4500					
4000					
3500					Early living cells
3000					
2500	Precambrian	Proterozoic			
2000					Buildup of free oxygen
1500					Formation of early supercontinents
1000					
800					Early multicelled organisms
570		Paleozoic	Cambrian		Breakup of early supercontinent
505			Ordovician		Early fishes
438			Silurian		Early land plants
408			Devonian		Early trees; coal
360			Carboniferous		Early reptiles
286			Permian		Formation of Pangea
245		Mesozoic	Triassic		Opening of Atlantic
208			Jurassic		
144	Phanerozoic		Cretaceous		
66		Cenozoic	Tertiary	Paleocene	Extinction of dinosaurs
57				Eocene	Separation of Australia
37				Oligocene	
24				Miocene	
5.3				Pliocene	
1.6			Quarternary	Pleistocene	
1.3					Homo Erectus
0.1					Neanderthal Man
0.01				Holocene	Modern Man

atmosphere of the early Earth. It has been speculated that the amino acids could have been formed in lightning storms, and other people suggest that they could have been transported to Earth in asteroids or comets. It is not really very important to us – all we need to know is that about 3 500 million years ago some absolute miracle occurred and the first living cells formed in some shallow sea or lake somewhere on this planet. And these living cells were able to divide and replicate.

These cells were nothing like the cells you and I are made of. They were very simple cells, with no central nucleus. Biologists today refer to bacteria and viruses as simple cells but these early cells may have been even less complicated than this.

Conditions in the shallow seas around the continental shelves and in the lakes and lagoons must have been ideal for these cells for they multiplied profusely and survived as such till about 2 200 million years ago. It is probable that they evolved and developed variations, but the essential thing is that they remained as single celled organisms.

But because they were so successful, there came a time when they had used up all the nutrients in the 'soup' in which they lived, this being their one source of energy, and a new variation of the cell evolved that could extract energy from the sun. What these cells did was use sunlight to split the water molecules into hydrogen and oxygen. The hydrogen they combined with the carbon that was available, to manufacture hydrocarbons. And the oxygen was released into the atmosphere.

Because sunlight was readily available and water was so abundant these cells, using photosynthesis, were extremely successful and dominated the tropical shallow waters of all the continents.

The oxygen in the atmosphere started to build up and some of it entered into the oceans and lakes through rainfall and wave action.

Now during the Earth's early history, there had been many fissures under the seas and one of the things they did was emit vast quantities of iron into the oceans. This iron happens to be soluble in water – but only in the absence of oxygen.

But when oxygen started entering the atmosphere and consequently into the seas, this iron readily formed iron oxide and was precipitated out. This happened in repeated cycles and we can see the results of this in iron deposits commonly found on Earth in the form of banded iron formations (BIFs). Various episodes of BIF formation took place, starting about 2 200 million years ago and going on to about 1 500 million years ago or even longer, indicating numerous cycles of oxygen formation.

The first multi-celled living organisms appeared on Earth only about 800 million years ago. Around 570 million years ago there was a huge explosion of species on the Earth and this was followed by land plants, then land reptiles, then reptile-like mammals and then mammals. The land plants assisted in the generation of oxygen into the atmosphere, as they do today, by soaking up some of the carbon dioxide in the atmosphere, using the carbon and giving off oxygen. At the time of the disappearance of the dinosaurs the only mammals around were small rodent-like animals. They might have survived because of their small size, and evolved into the various mammal species only some 65 million years ago. Our ancestors emerged less than a million years ago – just yesterday in the Earth's history.

And now, we homo sapiens, the most advanced intelligent creatures on the planet, burn up the oxygen in the atmosphere as we utilise the fossilised hydrocarbons to extract energy.

What does this tell us? One thing for sure is that we should keep an open mind when we go looking for life on other planets. What looks to us like very hostile conditions might, in fact, be ideal for the formation of living cells. Because that is how life on Earth started out.