

Dawn of the **animals**

What conditions led to the first animals – the mysterious Ediacara biota – gaining a precarious foothold on the evolutionary ladder? **Simon Poulton** explores the beginnings of life in the deep ocean.



The first animal? A cast of the quilted *Charnia*, the first accepted complex Precambrian organism. *Charnia* was once interpreted as a relative of the sea-pens.

The evolution and subsequent diversification of animal life is, at least in terms of humans, one of the most significant series of events to have shaped our planet. Yet, despite the obvious relevance to our own short history, we are only just beginning to piece together the early stages of animal evolution.

For more than three billion years of early Earth history, microbial life ruled the world. These ocean-living microbes were simple cells lacking a nucleus (prokaryotes), but they had a profound impact on the chemistry of the Earth's surface and atmosphere, ultimately creating an environment that allowed more complex life to evolve.

Evidence for this more advanced life, in the form of the first cells with a nucleus (eukaryotes), dates their evolution to somewhere between 2.7 and 1.8 billion years ago. But, these

first eukaryotes were still rather simple microscopic organisms. Significantly, their evolution appears to have proceeded rather slowly. It is much later in time, around 575 million years ago, that we find the first large multi-cellular organisms – the Ediacara biota – punctuating the fossil record. These soft-bodied, jellyfish-like organisms were typically centimetres to tens of centimetres in size, with some examples reaching more than a metre in length. The precise nature of the now extinct Ediacara biota remains unclear, but many scientists believe they were animals, with the suggestion that some forms may represent 'failed experiments' in animal evolution. Indeed, shortly after their evolution, most major groups of complex animals appeared in the fossil record, an event known as the Cambrian explosion. The Ediacaran

world represents a fascinating prelude to this apparent diversification of animal life.

But why did the Ediacara biota appear so suddenly in the fossil record, and why was the pace of eukaryote evolution apparently so slow up to then?

The answers to these questions are tied to the preceding environmental conditions. Over the last few years, new techniques for reading the rock record, combined with some rather revolutionary yet compelling lines of reasoning, have led to a re-evaluation of the history and consequences of the arrival of oxygen (oxygenation) on the Earth's surface.

The general consensus is that photosynthesising microbes in the surface ocean caused atmospheric oxygen levels to rise significantly around 2.3 billion years

The timing of the arrival of oxygen in the deep ocean has been contentious.

ago. They rose from essentially nothing to around 1-5 percent of modern values. Crucially, large animals have an oxygen threshold of about ten percent of modern levels: below that they are simply not viable. Researchers have long speculated that a second rise in atmospheric oxygen could have been responsible for the evolution of large complex life, but a lack of direct evidence for the timing of this rise has questioned its significance for animal evolution.

Of course, increases in atmospheric oxygen are only part of the story. The first Ediacarans are found in sediments deposited in the deep ocean, and hence, a more pertinent question relates to the precise timing of deep-ocean oxygenation, occurring as a direct result of rising atmospheric oxygen.

The timing of the arrival of oxygen in the deep ocean has been contentious. For

decades it was assumed that the deep ocean gained oxygen around 1.8 billion years ago. Purported evidence for this comes from the sudden disappearance of iron-enriched sediments, known as banded iron formations, from the rock record. It is well-established that these rocks form as a result of oxygen-free conditions in the deep ocean. So, the disappearance of these rocks could be related to a rise in ocean oxygen levels. However, biogeochemical modelling suggests that the modest rise in atmospheric oxygen, to levels believed to have occurred around 2.3 billion years ago, would be insufficient to oxygenate the deep ocean. We need an alternative explanation for the disappearance of these banded iron formations.

This second explanation calls for a change in the behaviour of the sulfur cycle. Oxygen in the atmosphere would lead to wide-scale oxidation of sulfide minerals on land. This would produce sulfate, which would flow down rivers to the sea, leading to increased sulfate concentrations in the ocean. Prior to this, geochemical evidence suggests that sulfate concentrations in the oceans were negligible.

The consequence of adding sulfate to an oxygen-free ocean would be a chemical reaction causing a dramatic increase in levels of highly toxic hydrogen sulfide. This would create a sulfidic ocean, similar to the modern Black Sea. Under sulfidic conditions, instead of the oceanic iron joining the sediments as iron oxides, iron would be removed as pyrite (iron sulfide), thus explaining the disappearance of banded iron formations about 1.8 billion years ago.

New models require testing, and the

search was on to provide direct evidence for the nature of ocean chemistry at this time. Based on several independent techniques, most notably measuring the amounts of iron in ocean sediments and analysing its nature, evidence for widespread sulfidic conditions beneath an oxygenated surface layer of the ocean has gradually come to light. Our work on well-preserved rocks from Ontario, Canada, has found that sulfidic conditions did indeed first occur coincident with the disappearance of banded iron formations, and apparently lasted for around one billion years. In such conditions, trace metals essential to life in the oceans would have been removed to the

sediments, potentially restricting the nitrogen cycle and creating an unfavourable environment for eukaryotes. Thus, sulfidic conditions provide an explanation for the protracted pace of eukaryotic evolution over this period. In addition, the lack of trace metals essential for photosynthesising microbes to produce oxygen would also explain why atmospheric oxygen levels remained at a relatively low level over this period.

If the hypothesis is correct, then oxic ocean conditions must have superseded oxygen-free conditions at a time broadly coincident with the first appearance of the Ediacara biota. Our recent evidence, again based on iron minerals, has found just this. The earliest known Ediacaran fossils occur on the Avalon Peninsula, Newfoundland,

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More information:

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around five million years after the final widescale ice age of the Precambrian period ended, 580 million years ago. The iron data suggest that the deep ocean was oxygen free during the glaciation, but became oxygenated shortly after, placing the second rise in atmospheric oxygen shortly before the evolution of the Ediacara biota. The reason for this rise in atmospheric oxygen is unclear, but it may have been a consequence of a flood of nutrients to the ocean during the melting of the continental ice sheets. This would stimulate a bloom in photosynthesising microbes, resulting in a huge pulse of oxygen into the atmosphere and ultimately into the deep ocean.

Although ecological and developmental factors likely also played a role, the fact that the first Ediacaran fossils occur within five million years of deep-ocean oxygenation implies a causal link between the two. This, at least to some extent, may explain the rather abrupt appearance of large animals in the fossil record. So the puzzle may be partly solved, but many questions remain. In particular, we might consider why the earliest known Ediacarans thrived in a deep ocean setting, when the oxygen apparently so vital for their evolution had already been abundant in shallow marine environments for millions of years. 🌸

