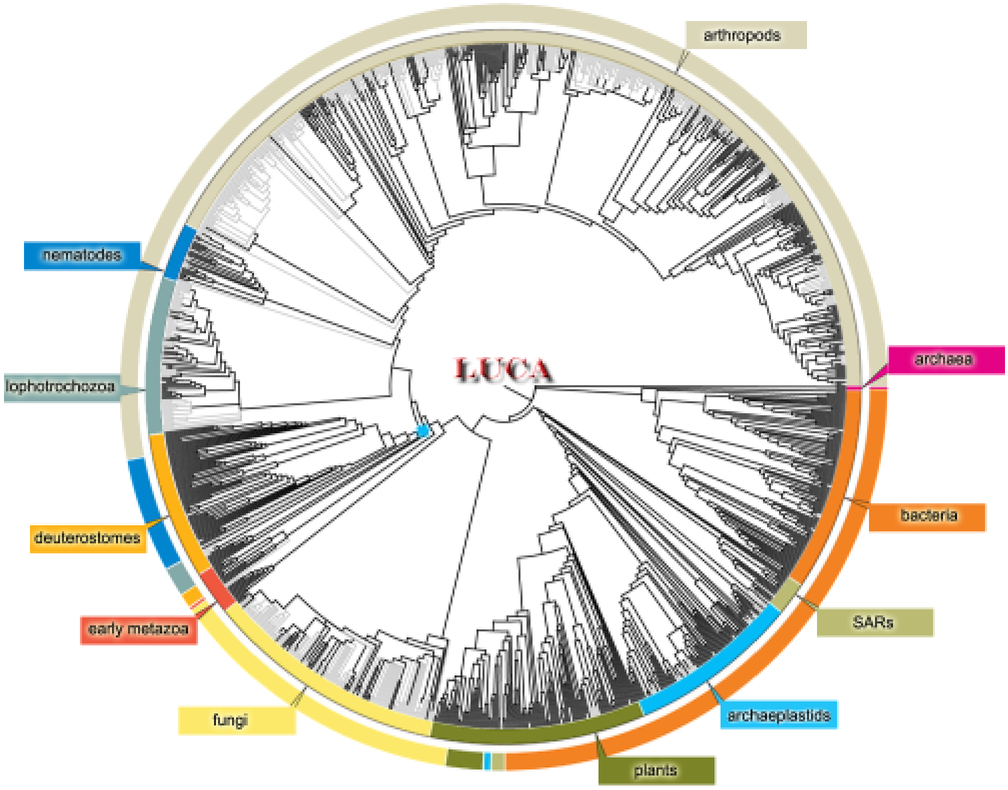
Palaeontology, palaeobiology and evolution

Earliest signs of vertebrates' ancestor? (*February 2017*)

Studies of DNA among living animals suggest that our own group, the vertebrates of the phylum Chordata, originated from a common ancestor that we share with echinoderms (sea urchins, star fish, sea cucumbers etc) and one of many worm-like phyla. This superphylum comprises the deuterostomes, but it is just one of several that encompass all animals and happens to be one of the smallest in terms of the number of living species that belong to it. We deuterostomes are vastly outnumbered by arthropods, nematodes, other worm-like creatures, molluscs, the rest of the animal kingdom and, of course, single-celled organisms, plants and fungi. Yet the DNA-based Circle of Life (Hinchcliff, C.E. and 21 others 2015. Synthesis of phlogeny and taxonomy into a comprehensive tree of life. *Proceedings of the National Academy of Sciences*, v. **112**, p. 12764-12769; DOI: 10.1073/pnas.1423041112) reveals that the deuterostome ancestral spoke originated early on in animal evolution.



The 'Circle of Life' (based on Hinchcliff *et* al. 2015; Fig. 1)

The majority of animals of all kinds are blessed with a mouth separate from means of expelling waste products and can be divided into two similar halves, hence their name bilaterians. The earliest fossils judged to be of this kind date to about 580 to 600 Ma ago, in the Doushantuo Formation of southern China, all of them visible only using microscopes. A DNA-based molecular clock hints at around 900-1000 Ma for the emergence of all animal body plans known today. Now another important time marker has turned up, again in sediments showing exquisite fossil preservation from China (Han, J. *et al*. 2017. Meiofaunal deuterostomes from the basal Cambrian of Shaanxi (China). *Nature*, v. **542**, p. 228-231; DOI:

10.1038/nature21072). The Chinese-British team of palaeontologists has found tiny, bag-like fossils preserved in phosphate, which have a mouth surrounded by folds and conical openings on either side of the body. They lived in limy muds on the sea bed now preserved as limestones at the base of the Cambrian System (541 Ma) and probably had a habit akin to worms in the most general sense. The authors sifted through 3 tonnes of rock to recover the fossils, rather than relying on a lucky hammer stroke.

Reconstruction of Saccorhytus coronarius (diameter about 1 mm) from the lowest Cambrian of Shaanxi, China. (credit: Han et al 1917)

Not especially prepossessing, the fossils are said to show more affinity to deuterostomes than anything else and to be the earliest known fossil examples. Yet the world's media pounced on them as the 'earliest known human ancestors', which is a bit rich as they could equally be the earliest sea urchins or may have led to several odd-looking fossils known only from the later Cambrian. It isn't possible to say with any certainty that they lie on the path that led to chordates and thus ourselves. Of course, that would not raise headlines in newspapers of record, such as Britain' Daily Telegraph, or on the BBC News website. The authors are much more honest, claiming only that the *Saccorhytus coronarius* fossils are probably deuterostomes whose affinities and later descendants are obscure. Their most important conclusion is that the cradle of our branch of animals lay in deep water muds laid down around the Precambrian-Cambrian boundary, ideal for subtly varied small, flabby creatures behaving like worms. Many more varieties probably remain to be found in similar rocks of the late Precambrian and slightly younger Cambrian when they are studied painstakingly in microscopic detail. A start has been made, that's all.

For more on early evolution see here and here

Dinosaurs in the flesh and feathers (*February 2017*)

Until only a few decades ago artistic portrayals of dinosaurs had them as leathery and scaled like lizards or crocodiles, as indeed rare examples of their fossilized skin seemed to suggest. The animatronic and CGI dinosaurs of the first Jurassic Park film were scary, but brownish grey. Later films in the franchise had them mottled and sometimes in colour, but still as mainly scaled leathery monsters. Reality soon overtook imagination as more and more exquisitely preserved fossils of small species were turned up, mainly in China, that were distinctly furry, fuzzy or feathered as shown below in a *Microraptor gui* fossil. It is now well-established that birds arose in the Jurassic from saurischian dinosaurs, the order that also included all of the large carnivorous dinosaurs as well as the many more nimble and diminutive ones whose feathers sometimes conferred an ability to glide or fly. Even the other main order, the ornithischia noted for hugeness and herbivory, has yielded fossil skin that suggest furry or feathered pelts. Once fur and feathers had been found, the next big issue became whether or not dinosaurs may have been as gaudy as many modern birds.

Fossil of a feathered dinosaur Microraptor gui from the early Cretaceous Jiufotang Formation in China (source: Wikipedia)

One of the first palaeobiologists to become immersed in the search for colourful dinosaurs was Jakob Vinther, now of Britain's Bristol University. In The March 2017 issue of *Scientific American* he summarises the progress that he and his colleagues have made (Vinther, J. 2017. The true colors of dinosaurs. *Scientific American*, v. **316(3)**, p. 42-49; DOI: 10.1038/scientificamerican0317-50). On his account, the major breakthrough was Vinther's discovery of tiny spherules in fossilised octopus ink that were identical to the granules of the pigment melanin that give the famous cephalopod 'smoke screen' its brownie-black colour. Melanin, or more precisely the melanosomes in which it is enclosed, is a key to coloration throughout much of the animal kingdom, especially in fur and feathers. There are two basic kinds, one conferring blackness and the other that imparts a rusty red hue, which combined with paleness due to lack of melanin together produce a gamut of greys, reds, browns oranges and yellows. Elongated melanosomes when lined up produce the phenomenon of interference fringes that yield iridescence, responsible for the bright colours of starlings, hummingbirds and some ducks when in bright light. There are other pigments, such as carotenoids (bright reds and yellows) and porphyrins (green, red and blue) that add to the gamut possible in animals, but it was melanosomes that captured Vinther's attention because of their importance in living feather colours.

Melanosomes occur in distinctively grouped assemblages, according to actual colour, and very similar microscopic structures turned up in the first fossil bird feathers that he studied. Others had assumed that they were bacterial colonies, which had grown during decay. The breakthrough was finding a fossil bird feather in which different structures were arranged in stripes; clear signs of patterning. Vinther's concept bears fruit in a range of furry and feathered dinosaurs. One (*Anchiornis*) with a black and white body and limb speckles had a bright red crest and another (*Sinosauropterix*) was ginger over its back with a tiger striped tail and a white underside; an example of countershaded camouflage. His team has even been able to assign different kinds of patterning to a variety of possible habitats. Given superbly preserved specimens it seems likely that dinosaur and bird coloration may be traceable back more than 200 Ma.

Artist's impression of the small theropod dinosaur Microraptor showing colours predicted by analysis of melanosomes on its feathers.(credit: Wikipedia)

Another aspect of the filmic licence in Jurassic Park was its hinging on preservation of genetic material from the Mesozoic, specifically in a parasite preserved in amber, so that the creatures could be resurrected by bio-engineering. The only relevant, real find is a 46 Ma old mosquito whose abdomen was blood-engorged when it was fossilised. But all that remains are high iron concentrations in porphyrins; break-down products of haemoglobin. Given that fossil DNA can only be reassembled in digital form from millions of fragmentary strands found in fossils that corresponds to the order of AGCT nucleobases that is barely likely to be possible – the oldest full genome yet analysed is that of a 700 ka horse. However, another biological material that varies hugely among living animals, protein, has proved to be tractable, albeit in a very limited way. Frozen mammoth meat, somewhat bloody, is sometimes unearthed from Siberian permafrost, but according to one Russian mammoth expert even the best preserved is inedible.

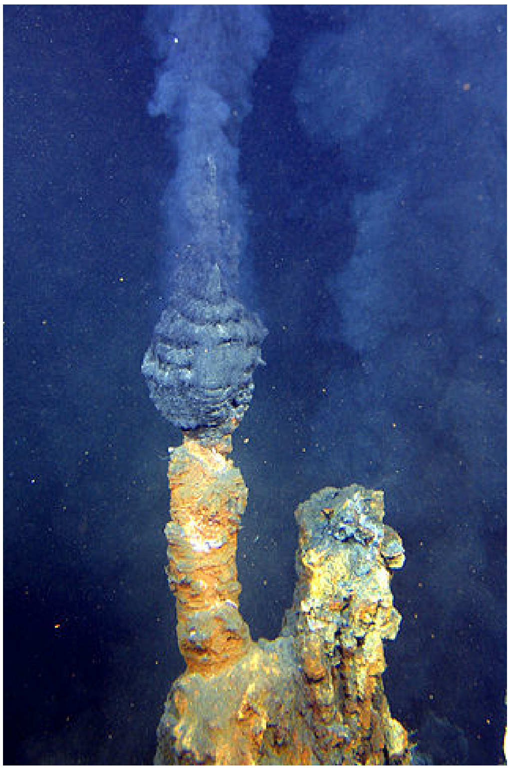
Beyond the Pleistocene the search for fossilised proteins has been hesitant and deeply controversial, particularly in the case of that from dinosaurs, for the obvious reason of publicity suspicions. But again, it is a story of persistence and patience. Mary Schweitzer of North Carolina State University claimed in 2007 that she had found some, but was howled down by other palaeontologists on the issues of its unlikely survivability and contamination. But other researchers had pushed back the age limits. By repeating their earlier analyses with the greatest possible care, Schweitzer's team confirmed their earlier results with several strands of the protein collagen about 15 amino acids in length from an 80 Ma old duck-billed dinosaur. Moreover they were able to show a closer affinity of the partial proteins to those of modern birds than to other reptiles, tallying with tangible fossil evidence (Schroeter, E.R and 8 others 2017. Expansion for the Brachylophosaurus canadensis Collagen I Sequence and Additional Evidence of the Preservation of Cretaceous Protein. *Journal of Proteome Research*, v. **16**, p. 920-932, DOI**:** 10.1021/acs.jproteome.6b00873). The work continues for other dinosaurs and early fossil birds, with better reason for confidence and a chance of tying-down genetic relatedness. Another approach shows that collagen may still be preserved in a Jurassic (195 Ma) sauropod dinosaur's rib (Lee, Y-C. and 9 others 2017. Evidence of preserved collagen in an

Early Jurassic sauropodomorph dinosaur revealed by synchrotron FTIR microspectroscopy. *Nature Communications*, v. **8** doi:10.1038/ncomms14220).

See also: Service, R.F. 2017. Researchers close in on ancient dinosaur remains. *Science* (News in depth), v. **355**, p. 441- 442.

Earliest hydrothermal vents and evidence for life (*March 2017*)

That seawater circulates through the axial regions of rifts associated with sea-floor spreading has been known since well before the acceptance of plate tectonics. The idea stems from the discovery in 1949 of brines with a temperature of 60°C on the central floor of the Red Sea, which in the early 60s turned out to be anomalously metal-rich as well. Advanced submersibles that can withstand the high pressures at great depth a decade later produced images of swirling clouds of sediment from large sea-floor springs, first on the Galapagos rift and subsequently on many others. The first shots were of dark, turbulent clouds, prompting the term 'black smoker' for such hydrothermal vents and it turns out that others produce light-coloured clouds – 'white smokers'. Sampling revealed that the sediments in black smokers were in fact fine-grained precipitates of metallic sulfides, whereas those forming white smokers were sulfates, carbonates and oxides of barium calcium and silicon also precipitated from solute-rich brines produced by partial dissolution of ocean floor through which they had passes.



A black smoker with associated organism. (credit: Wikipedia)

Excitement grew when hydrothermal vents were shown to have complex animal ecosystems completely new to science. A variety of chemical evidence, most importantly the common presence of proteins and other cell chemicals built around metal sulfide groups in most living organisms, prompted the idea that hydrothermal vents may have hosted the origins of life on Earth. Many fossil vent systems also contain fossils; macrofossils in the Phanerozoic and microbial ones from the Precambrian. But tangible, if debateable, signs of life, in the form of mats ascribed to bacteria or archaea holding together fine-grained sediments, go back no further than 3830 Ma in the Isua area of SW Greenland (see *Signs of life in some of the oldest rocks* September 2016) . Purely geochemical evidence that carbonaceous compounds may have formed in living systems are ambiguous since quite complex hydrocarbons can be synthesised abiogenically by Fischer-Tropsch reactions between carbon monoxide and hydrogen. Signs of deep sea hydrothermal activity are common in any geological terrain containing basalt lavas with the characteristic pillows that indicate extrusion beneath water. So to trace life's origins all that is needed to trigger the interest of palaeobiologists are the oldest known pillow lavas. Until quite recently, that meant the Isua volcano-sedimentary association, but heating, high pressures and strong deformation affected those rocks when they were metamorphosed half a billion years after they were formed; a cause for skepticism by some geoscientists.

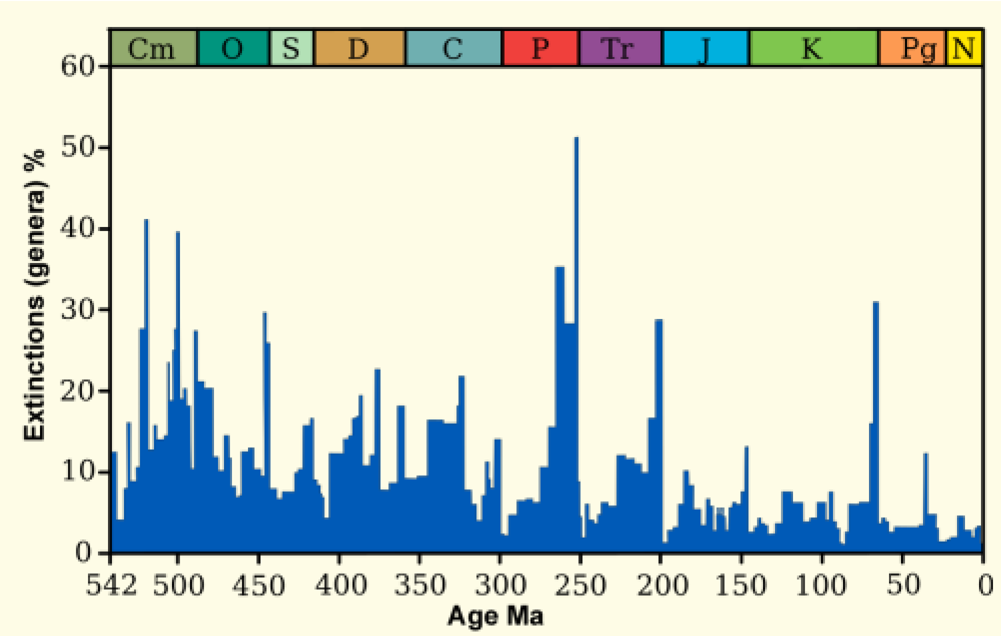
The primacy of Isua metavolcanic rocks has been challenged by more extensive metamorphosed basalts in the Nuvvuagittuk area on the east side of Hudson Bay in Quebec, Canada. They contain hydrothermal ironstones associated with pillowed basalts that are cut by more silica-rich intrusive igneous rocks dated between 3750 and 3775 Ma. That might place the age of basalt volcanism and the hydrothermal systems in the same ball park as those of Isua, but intriguingly the basalts' ^{146}Sm-^{142}Nd systematics suggest a possible age of magma separation from the mantle of 4280 Ma (this age is currently disputed as it clashes with U-Pb dates for zircon grains extracted from the metabasalts, around the same as the age at Isua). Nonetheless, some parts of the Nuvvuagittuk sequence are barely deformed and show only low-grade metamorphism, and they contain iron- and silica-rich hot spring deposits (Dodd, M.S. *et al*. 2017. Evidence for early life in Earth's oldest hydrothermal vent precipitates. *Nature*, v. **543**, p. 60-64; DOI: 10.1038/nature21377). As at Isua, the ironstones contain graphite whose carbon isotope proportions have an ambiguous sign of having formed by living or abiotic processes. It is the light deformation and low metamorphism of the rocks that gives them an edge as regards being hosts to tangible signs of life. Extremely delicate rosettes and blades of calcium carbonate and phosphate, likely formed during deposition, remain intact. These signs of stasis are in direct contact with features that are almost identical to minute tubes and filaments formed in modern vents by iron-oxidising bacteria. All that is missing are clear signs of bacterial cells. Ambiguities in the dating of the basalt host rocks do not allow the authors claims that their signs of life are significantly older than those at Isua, but their biotic origins are less open to question. Neither offer definitive proof of life, despite widespread claims by media science correspondents, some of whom tend metaphorically to 'run amok ' when the phrase 'ancient life' appears; in this case attempting to link the paper with life on Mars …

You can find more on early life here

The late-Ordovician mass extinction: volcanic connections (*July 2017*)

The dominant feature of Phanerozoic stratigraphy is surely the way that many of the formally named major time boundaries in the Stratigraphic Column coincide with sudden shifts in the abundance and diversity of fossil organisms. That is hardly surprising since all the globally recognised boundaries between Eras, Periods and lesser divisions in relative time were, and remain, based on palaeontology. Two boundaries between Eras – the

Palaeozoic-Mesozoic (Permian-Triassic) at 252 Ma and Mesozoic-Cenozoic (Cretaceous-Palaeogene) at 66 Ma – and a boundary between Periods – Triassic-Jurassic at 201 Ma – coincide with enormous declines in biological diversity. They are defined by mass extinctions involving the loss of up to 95 % of all species living immediately before the events. Two other extinction events that match up to such awesome statistics do not define commensurately important stratigraphic boundaries. The Frasnian Stage of the late-Devonian closed at 372 Ma with a prolonged series of extinctions (~20 Ma) that eliminated at least 70% of all species that were alive before it happened. The last 10 Ma of the Ordovician period witnessed two extinction events that snuffed out about the same number of species. The Cambrian Period is marked by 3 separate events that in percentage terms look even more extreme than those at the end of the Ordovician, but there are a great many less genera known from Cambrian times than formed fossils during the Ordovician.



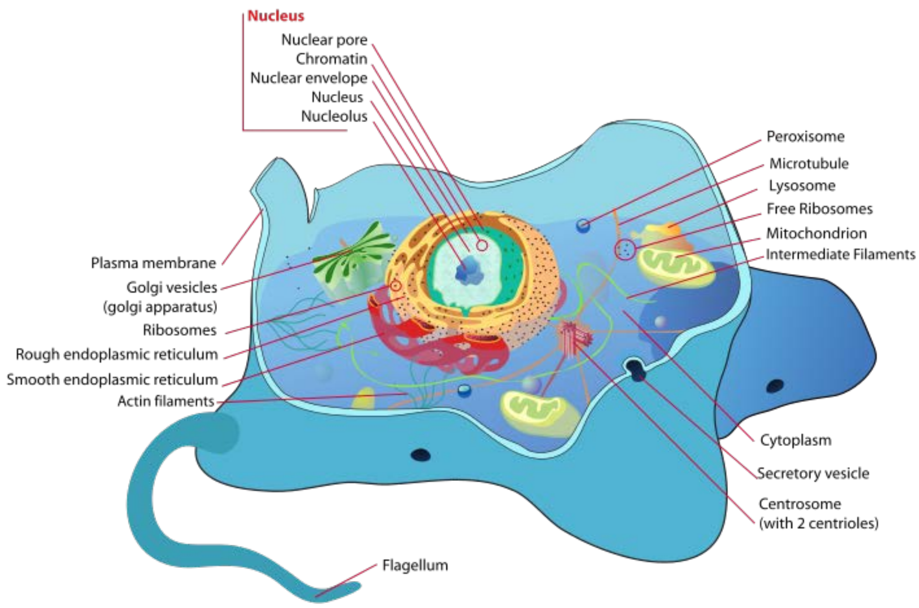
Faunal extinctions during the Phanerozoic in relation to the Stratigraphic Column.

Empirical coincidences between the precise timing of several mass extinctions with that of large igneous events – mainly flood basalts – suggest a repeated volcanic connection with deterioration of conditions for life. That is the case for four of the Famous Five, the end-Ordovician die-off having been ascribed to other causes; global cooling that resulted in south-polar glaciation of the Gondwana supercontinent and/or an extra-solar gamma-ray burst (predicated on the preferential extinction of Ordovician near-surface, planktonic fauna such as some trilobite families). Neither explanation is entirely satisfactory, but new evidence has emerged that may support a volcanic trigger (Jones, D.S. *et al*. 2017. A volcanic trigger for the Late Ordovician mass extinction? Mercury data from south China and Laurentia. *Geology*, v. **45**, p. 631-634; DOI: 10.1130/G38940.1). David Jones and his US-Japan colleagues base their hypothesis on several very strong mercury concentrations in thin sequences of late Ordovician marine sediments in the western US and southern China that precede, but do not exactly coincide with, extinction pulses. They ascribe these to large igneous events that had global effects, on the basis of similar Hg anomalies associated with extinction-related LIPs. Yet no such volcanic provinces have been recorded from that time-range of the Ordovician, although rift-related volcanism of roughly that age has been reported from Korea. That does not rule out the possibility as LIPs are known from parts of the modern ocean floor that formed in the Mesozoic and Cenozoic, such as the Ontong Java Plateau. Ordovician ocean floor was subducted long ago.

The earlier Hg pulses also coincide with evidence for late Ordovician glaciations over what is now Africa and eastern South America. The authors suggest that massive volcanism may then have increased the Earth's albedo by blasting sulfates into the stratosphere. A similar effect may have resulted from chemical weathering of widely exposed flood basalts which draws down atmospheric CO_2. The later pulses coincide with the end of Gondwanan glaciation, which may signify massive emanation of volcanic CO_2 into the atmosphere and global warming. Despite being somewhat speculative, in the absence of evidence, a common link between the Big Five plus several other major extinctions and LIP volcanism would quieten their popular association with major asteroid and/or comet impacts currently being reinvigorated by drilling results from the K-Pg Chicxulub crater offshore of Mexico's Yucatan Peninsula.

The rise of the eukaryotes (*December 2017*)

You and I, and all the living things that we can easily see belong to the most recently evolved of the three great domains of life, the Eukarya. The vast bulk of organisms that we can't see unaided are prokaryotes, divided into the Bacteria and the Archaea. Their genetic material floats around in their cell's fluid, while ours resides mainly in the eukaryote cell's nucleus with a bit in various organelles known as mitochondria and the chloroplasts of plant cells. Unlike the chicken and egg question, that concerning which came first, prokaryotes or eukaryotes, is answered by DNA. Eukaryote DNA contains a lot from prokaryotes, but the converse does not hold. That contrast posed the question of how eukaryotes arose from the two earlier, simpler forms of life, the answer to which Lynn Margulis suggested to be a whole series of symbiotic relationships among various prokaryotes that shared a host cell; her hypothesis of endosymbiosis. Now, the vast majority of eukaryotes depend on free oxygen for their metabolism, so when the first of them arose boils down to the period of geological history following the Great Oxidation Event around 2.4 billion years ago.



Structure of a typical eukaryote (animal) cell (Credit: Mariana Ruiz)

Molecular-clock estimates based on the range of variation in the genomes of a wide range of eukaryotes suggest it took place sometime between 1000 and 2000 Ma. A better means of homing in on a date for the Last Eukaryote Common Ancestor (LECA – as opposed to that of the first organism LUCA) would be that of the earliest fossil to show eukaryote affinities. *Grypania* from 1.85 Ga, a sort of whorl-like fossil, is a good candidate and is widely thought to be the earliest of our kind but lacks signs of actual cells. More convincing fossils – known generically as acritarchs – from times between 1.5 and 1.0 Ga look like primitive fungi, red algae and slime moulds. A comprehensive review of the microfossils of the Palaeoproterozoic (2.5 to 1.6 Ga) includes both prokaryotes and probable early eukaryotes (Javaux, E.J. & Lepot, K. 2017. The Paleoproterozoic fossil record: Implications for the evolution of the biosphere during Earth's middle-age. *Earth Science Reviews*, v. **176**, p. 68-86; doi: 10.1016/j.earscirev.2017.10.0001). Yet, despite rapidly accumulating evidence, especially from rocks in China, the picture remains one of monotony; for instance *Grypania* spans the best part of half a billion years. Bacteria and Archaea cannot be distinguished easily in the absence of preserved DNA. Despite evidence for oxygen in the oceans and atmosphere, apart from a few shallow-water oxygenated examples the chemistry of Palaeoproterozoic marine sediments is dominated by mineralogical outcomes of reducing chemistry. Many chemical isotopic environmental proxies 'flat-line' to the extent that the early Proterozoic is sometimes referred to as the 'boring billion', yet our ultimate precursors were part of the marine ecosystem. That is, unless one accepts the possibility that that fossils labelled 'eukaryote' are colonial prokaryotes – evidence for cell nuclei is sparse. Endosymbiosis, although an attractive model for eukaryote origins, is not proven. The reason for lingering scepticism is that there are only a tiny number of modern examples of prokaryote cells ending up inside those of other prokaryotes.

Whatever, chemical biomarkers in sediments older than about 720 Ma indicate that prokaryotes were the only notable primary producers in the oceans until the Neoproterozoic. Microscopic fossils that are inescapably eukaryotes in the form of amoeba suddenly emerge around that time. This development from the lingering marginality of early eukaryotes to thriving ecosystems that they dominated thereafter is a puzzle seeking a plausible explanation. It coincides with the onset of the Snowball Earth glaciations of the Cryogenian Period (850 to 635 Ma) and a rise in atmospheric and presumably oceanic oxygen. Then macroscopic eukaryotes 'bloomed' into distinctively different forms in the Ediacaran Period (635 to 541 Ma) and thereafter. Before the Cryogenian we can perhaps regard eukaryan life and the endosymbiosis that may have given rise to it as a series of ecological experiments repeatedly knocked-back by chemical conditions and competition with the vastly more abundant prokaryotes.