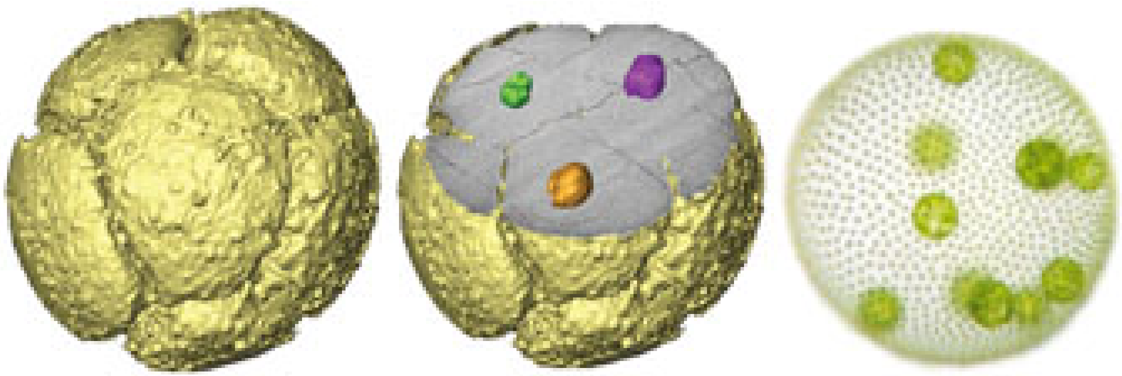
Palaeontology, palaeobiology and evolution

Excitement over early animals dampened (*January 2012*)

The Neoproterozoic *lagerstätte* in the Doushantuo Formation in the south of China was until recently thought to be a source of astonishing information about Earth's earliest animals (see Ancestral animal? August 2004) that preceded the appearance of those with hard parts at the start of the Phanerozoic. It contains well-preserved fossils that resemble embryos, algae, acritarchs, and small bilaterians. Dated at between 580 to 600 Ma (See Age range of early fossil treasure trove February 2005), the Doushantuo directly overlies cap carbonates representing the emergence of Earth's climate from a Snowball epoch, which is represented by a tillite beneath the carbonate sequence. A detailed examination using synchrotron X-ray tomography of the putative animal embryos does show clear signs of cell doubling or palintomy (Huldtgren, T. *et al*. 2011. Fossilized nuclei and germination structures identify Ediacaran 'animal embryos' as encysting protists. *Science*. V. **334**, p. 1696-1699) but also internal cell features most likely to be nuclei, but which have no counterparts in animal embryos.



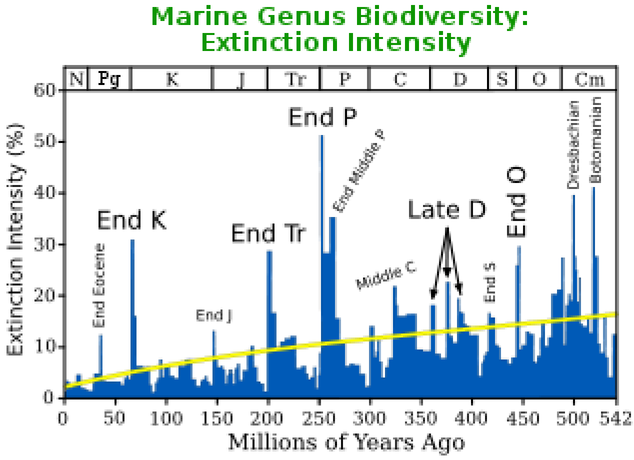
Left – surface of spherule from Doushantuo formation; centre – slice through X-ray tomogram (Credits: Huldtgren *et al*. 2011); right – modern Volvox cyst (Image 1 mm across)

The organisms which the fossils most resemble are indeed eukaryotes, but of a kind separate from animals known as Holozoa. Yet there are striking resemblances with eukaryotes more distant from animals, such as the modern *Volvox*, a type of alga (Butterfield, N.J. 2011. Terminal developments in Ediacaran embryology. *Science*. V. **334**, p. 1655-1656), that developed from an ancestor further back in time than the separation of metazoan animals from holozoans.

Related articles: Dead Fossils Tell the Best Tales (news.sciencemag.org); Protists, not animals (freethoughtblogs.com)

Late Devonian: mass extinction or mass invasion?

The later part of the Devonian (the Frasnian and Famennian Stages) once marked the second largest marine mass extinction (~375 Ma) of the Phanerozoic Eon: it was one of the 'Big Five'. For the last decade the drop in marine biodiversity in that interval has come under scrutiny: partly because it may have involved several events; no well-supported extinction mechanism has emerged; and extinctions seem have been concentrated on three animal groups – trilobites, brachiopods and reef corals. Something large did happen, as reef-building corals almost disappeared and coral reefs only returned with the rise of modern (scleractinian) corals in the Mesozoic. While the end of the Devonian still figures widely as having experienced a mass extinction event, more detailed palaeontological work at the genus and species level suggests another possibility.



Mass extinctions

'Officially' a mass extinction event must exceed the background extinction rate throughout the Phanerozoic and be above that in immediately preceding and following stages: statistically significant, that is. They always give rise to a marked reduction in biodiversity, but another mechanism can do that without extinctions suddenly increasing. The rate at which new species emerge can fall below that of species extinctions, when the overall number of living species falls. As far as ecosystems are concerned both processes are equally severe, but the causes may be very different.

Brachiopod (*Hederella*) from the Devonian of Ohio, USA.

Reviewing detailed records of Devonian species of two genera of brachiopods and one bivalve genus (50 species in all) in five North American stratigraphic sequences, Alycia Stigall of Ohio University, USA noted apparently significant variations in the local assemblages (Stigall, A. L. 2012. Speciation collapse and invasive species dynamics during the Late Devonian 'Mass Extinction'. *GSA Today*, v. **22**(1), p. 4-9; DOI: 10.1130/g128a.1). Speciation overall fell in the Frasnian and the preceding Givetian, while rate of extinction barely changed. For the three studied genera, speciation reached low values in the Frasnian and

Famennian, but that was accompanied by an equally large fall in extinctions. In this narrow sample we seem to be seeing not an extinction crisis but one of biodiversity. Why?

The Late Devonian saw repeated ups and downs in sea level, which repeatedly connected and disconnected shallow- to moderate-depth marine basins. The fossil record shows repeated cases of species from one basin colonising another, each invasion accompanying rapid marine transgression. One means whereby species arise is through prolonged isolation of separate populations of the ancestral species through independent genetic drift and mutation. The episodic connection of basins may have prevented such allopatric speciation. Interestingly, the invading species were dominantly animals with a broad tolerance for environmental conditions.

Whether this mechanism applied to all three main animal groups whose diversity plummeted in Late Devonian times remains to be seen, and it begs the question 'why didn't it happen among other animal groups that were less affected by whatever the events were?' One of the problems associated with decreasing biodiversity in modern marine (and terrestrial) settings is growth in the numbers of invasive species, so the work on 375 Ma fossils might help understand and mitigate current ecological issues. The only difference is that for many of the hyper-successful invader species the means of invasion has been provided by human activities. brachiopod brachioopod

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Mesozoic fleas (*Mrch 2012*)

Strange as it might seem, rather than bringing to mind the opening pages of Michael Crichton's *Jurassic Park* 'ancient fleas' suggest to me Frederick Engels's *Dialectics of Nature* (1883). In his lampoon of determinism, which might today be directed at a famous evolutionary biologist, Engels wrote:

'…*last night I was bitten by a flea at four o'clock in the morning, and not at three or five o'clock, and on the right shoulder and not on the left calf – these are all facts which have been produced by an irrevocable concatenation of cause and effect, by an unshatterable necessity of such a nature indeed that the gaseous sphere, from which the solar system was derived, was already so constituted that these events had to happen thus and not otherwise*.'

But a paper about fossil fleas from the time of the dinosaurs was always going to catch the eye (Huang, D. *et al*. 2012. Diverse transitional giant fleas from the Mesozoic era of China. *Nature*, v. **483**, p. 201-204; DOI: 10.1038/nature10839), and that they come from China does have an element of inevitability that arises from that country's rich endowment with sites of exceptional preservation. The fleas are not at all like the shiny creatures that are so difficult to trap in the fur of a cat's ear, and they are big: up to 2 cm long. Two species come from Middle Jurassic and one from the Lower Cretaceous. The fascinating thing about fleas, however, is that they evolved to live and thrive in fur and feathers. This niche is signified by their claws, whose form and articulation avoid entanglement with fibres: which is why cat fleas are so nimble. While cat fleas are flattened laterally to help them slip though fur and have powerful legs that allows them to leap from host to host, the Mesozoic fleas are flat from back to front and are not so leggy.

Giant Mesozoic fleas from China, 1.4 and 0.8 cm long. (Credit: Huang *et al*. 2012)

Being so large, it seems unlikely that these Mesozoic fleas would have parasitized mammals that were probably far smaller on average than now. But by the Jurassic fossil evidence, largely from China, shows that dinosaurs had developed feather-like cover. Their evolution itself created a niche occupied thereafter by fleas and other bloodsuckers. They are wingless relatives of flies (Order: Diptera) that first appear in the Triassic fossil record, both thought to have stemmed from more primitive scorpionflies (Order: Mecoptera)

Related articles: When Flea-Rex was pain in the neck for T-Rex – South China Morning Post (subscription) (topics.scmp.com); Giant Jurassic fleas sucked but couldn't jump (blogs.discovermagazine.com)

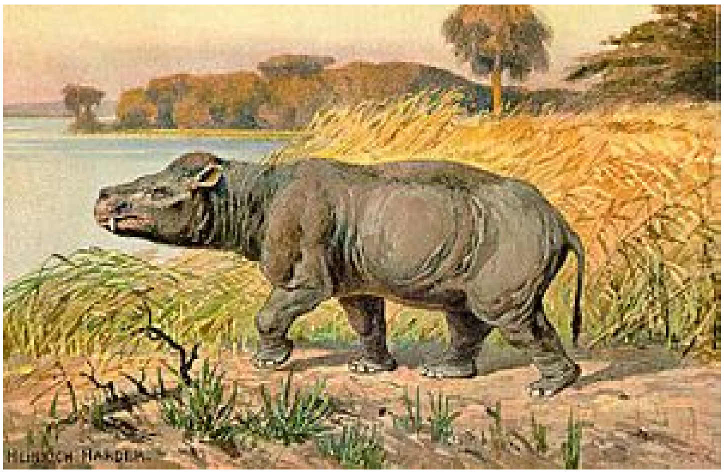
Tiny shrinking horses (*March 2012*)

The earliest known ancestors of modern horses occur in Palaeogene mammal-rich terrestrial sediments of the northwestern US, particularly those of the Wind and Bighorn Basins. The first with clear horse-like features was *Sifrhippus* (formely *Eohippus,* or *Hyracotherium*), but famously it had four hoofed toes and was about the size of a household cat. Subsequent development to a single load-bearing toe has long formed one of the classic cases for evolution. *Sifrhippus* lived at the end of the Palaeocene. From the large numbers of well-preserved skeletons, this was a herding animal. The large numbers of fossils have also made it a candidate for testing a hypothesis that individuals of a mammal and bird species become smaller as climate warms: Bergmann's Rule. The background to this view is that in modern warm-blooded or endothermic animal species individuals tend to be smaller the closer they are to the Equator.

Reconstruction of *Sifrhippus*.

The end of the Palaeocene was marked by a now well-documented rise in global surface temperature that left a marked sign of increased ^{13}C in sediments spanning the Palaeocene-Eocene boundary, which is widely believed to have resulted from massive exhalations of methane from the seafloor. Bergmann's Rule arose because there appears to be a general decrease in size of most mammal fossils through the P-E Thermal Maximum. *Sifrhippus* lived through the event and indeed did undergo 30% decrease in size at the start of the carbon-isotope shift marking the PETM. Moreover, after the isotopic excursion its fossils indicate a 70% increase in size (Secord, R. and 8 others 2012. Evolution of the earliest horses driven by climate change in the Paleocene-Eocene Thermal Maximum. *Science*, v. **335**, p. 959-962; DOI: 10.1126/science.1213859).

The study centres on *Sifrhippus* and other mammals over a period representing several thousand generations. It broke new ground in two ways: it used the size of the horses' teeth to estimate body mass, and teeth of a variety of mammals afforded systematic measurements of both carbon and oxygen isotopes. The carbon isotopic analyses pin-pointed the span of the PETM locally, while oxygen isotopes charted local changes in average temperature. The results show remarkable coherence with Bergmann's Rule, but reveal other interesting aspects of the PETM in North America. Oxygen-isotope in the teeth of different mammal species give some idea of their diet and habitat. *Sifrhippus* shows the highest enrichment of ^{18}O in its teeth, which suggests that it ate leaves from which water evaporation selectively removed the lighter ^{16}O, i.e. in open, dry areas. Another ubiquitous fossil, *Coryphodon*, consistently has lower ^{18}O than other mammals, signifying that it was water-loviong and ate aquatic plants, i.e. not subject to evaporation. Matching O-isotopes for the two species across the PETM shows a greater shift in ^{18}O for *Sifrhippus* than for Coryphodon, which suggests that hidden in the O-isotope record of temperature is information about rainfall variations during the PETM. To further support Bergmann's Rule, changes in the size of *Sifrhippus*, do *not* correlate with the aridity index. So it seems that heat alone was responsible for dwarfing – the other possibility considered by the researchers was that decreased availability or quality of diet could have been responsible.



Reconstruction of Coryphodon.

Related articles: Little People: Will Climate Change Shrink the Species? (ecocentric.blogs.time.com)

A cuddly tyrannosaur; whatever next? (*April 2012*)

Feathered and fluffy dinosaurs in the families that may have led to birds have become almost commonplace, thanks to wonderful preservation in some Chinese Mesozoic sedimentary rocks (see *Flying feathers* March 2003) and what has become a cottage industry for local people, under professional direction. Most have been small theropods in the Coelurosauria taxonomic branch that span the Jurassic and Cretaceous Periods. The famous Lower Cretaceous Liaoning lagerstätte in NE China recently yielded something truly awesome: three well-preserved specimens of a feathered dinosaur almost as large as the giant tyrannosaurs of the Late Cretaceous (i.e. > 1 t in life) (Xu, X. *et al*.2012. A gigantic feathered dinosaur from the Lower Cretaceous of China. *Nature*, v. **484**. P. 92-95; DOI: 10.1038/nature10906). In fact *Yutyrannus huali* ('beautiful feathered tyrant)is a member of the same subgroup as the Upper Cretaceous *T. rex* and was clearly a top predator in its day.

Feathered dinosaur Deinonychus (Credit: Aaron Gustafson)

Equally fortuitous is that the three specimens comprise one with a living body weight of about 1.4 t, the other two being between 500 and 600 kg. Various differences between the largest and the two smaller individuals suggest that thee find represents two generations, the largest perhaps 8 years older than the two smaller ones. All three preserve densely packed filaments suggesting that they were fluffy rather than truly feathered. So why the difference from its probably scaly relative tyrannosaurs from about 50 Ma later?

Around 125 Ma global climate was considerably cooler than the Late Cretaceous greenhouse world, Liaoning probably having mean annual air temperatures around 10°C compared with 18°C late in the Period. *Yutyrannus huali* and some of its contemporary theropods probably evolved high TOG insulation to ensure all-season sprightliness. It is also possible that a display function was also involved, as seems to have been the case for other dinosaurs.

Related articles: One-Ton Feathered Dinosaur Found: Fluffy and Fierce (news.nationalgeographic.com)

Large-animal extinction in Australia linked to human hunters (*April 2012*)

Between 13 and 11.5 ka, around 30 species of large herbivorous mammals became extinct In North America. Much the same occurred in Australia around 45 ka. Both cases roughly coincided with the entry of anatomically modern humans, where neither they nor earlier hominids had lived earlier. Such extinctions are not apparent in the Pleistocene records of Africa or Eurasia. An obvious implication is that initial human colonisation and a collapse of local megafaunas are somehow connected, perhaps even that highly efficient early hunting bands slaughtered and ate their way through both continents. But other possibilities can not be ruled out, including coincidences between colonisation and climate or ecosystem change. As many as thirteen different hypotheses await resolution. One inevitably makes headline news repeatedly: that both the early Clovis culture and North American megafaunas met their end around the same time as the start of the Younger Dryas millennial cold snap because a meteorite exploded above North America (see *Comet slew large mammals of the Americas* March 2009).

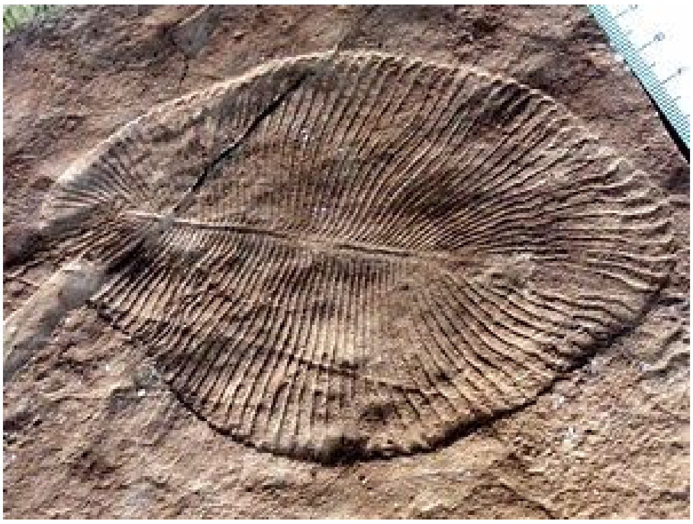
One problem in assessing the various ideas is accurately dating the actual extinctions, partly because terrestrial environments rarely undergo the continual sedimentation that builds up easily interpreted stratigraphic sequences. Another is that it is not easy to prove, say, that all giant kangaroos died in a short period of time, because of the poor record of preservation of skeletons on land. A cautionary tale concerns the demise of the woolly mammoth that roamed the frigid deserts of northern Eurasia that definitely was hunted by both modern humans and Neanderthals. It was eventually discovered that herds still survived on Wrangell Island until the second millennium BC. There is a need for a proxy that charts indirectly the fate of megafaunas plus accurate estimates of the timing of human colonisation. In North America there is a candidate for the first criterion: traces of the fungus *Sporormiella* (see *Fungal clue to fate of North American megafauna* January 2010) that exclusively lives in the dung of large herbivores. Fungal spores get everywhere, being wind-dispersed, and in NE US lake cores they fell abruptly at about 13.7 ka. *Sporormiella* needs to pass through the gut of herbivores to complete its life cycle. The same genus of fungus breaks down dung in Australia.

Aboriginal Rock Art, Kakadu National Park, Australia

Measuring spore content in sediment on the floor of a Queensland lake shows the same abrupt decline in *Sporormiella* abundance at between 43 to 39 ka before present (Rule, S. et al. 2012. The aftermath of a megafaunal extinction: ecosystem transformation in Pleistocene Australia. Science, v. *335*, p. 1483-1486; DOI: 10.1126/science.1214261). Moreover, the fungal collapse is accompanied by a marked increase in fine-grained charcoal – a sign of widespread fires – and is followed by a steady increase in the pollen of scrub vegetation at the expense of that of tropical rain forest trees. The shifts do not correlate with any Southern Hemisphere climatic proxy for cooling and drying that might have caused ecosystem collapse. That still does not mark out newly arrived humans as the culprits, as the early archaeological record of Australia, as in North America, is sparse and only estimated to have started at around 45 ka. Yet this is quite strong circumstantial evidence. The 20 or more animals – marsupials, birds and reptiles – with a mass more than 40 kg that formerly inhabited the continent would probably have been 'naive' as regards newly arrived, organised, well-armed and clever new predators, as would those of North America and much later in New Zealand, and would have been 'easy prey'. Incidentally, faunas of both Africa and Eurasia are usually wary of humans, possibly as a result of a far longer period of encounters with human hunter-gatherers. In Australia's case, the use of deliberate fire clearing to improve visibility of game may have had a major role, although it is equally likely that the demise of large herbivores would have left large amounts of leaf litter and dry grasses to combust naturally. Yet the Earth as a whole around 40 ka was slowly cooling and drying towards the last glacial maximum around 20 ka, so human influence may merely have pushed the megafauna towards extinction, such is the fragility of Australia's ecosystems.

Origin of the animals' arms race (*April 2012*)

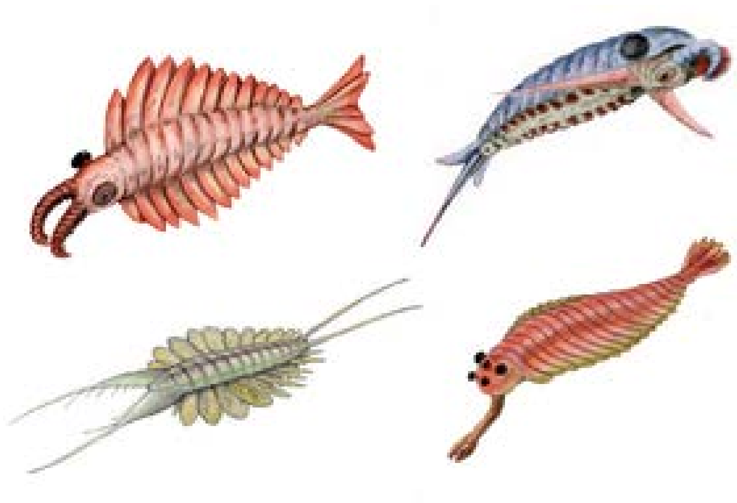
Palaeontologists generally agree on one broad aspect of animal evolution: the central role of predation versus defence in animal diversification to occupy different ecological niches. Indeed that co-relation has to an extent been responsible for the diversification of potentially habitable niches themselves. Armour and arms form a dialectic within the animal world, but one that only rose to dominate when hard materials became an integral part of animal morphology, allowing some to bite, gnaw or rasp and others to develop shelly or horny skeletons. The eukaryote Kingdom Animalia is united by one life style, that of feeding directly or indirectly on other living things. They are heterotrophs unable to generate energy and tissue through the fundamental harnessing of chemistry and physics to use the inorganic world directly, as do autotrophs. One of the earliest discoveries about the history of animals was that fossils in the widely accepted meaning of the word appeared suddenly in the geological record, earlier rocks containing virtually no tangible signs of life: fossils explode in numbers after the start of the Cambrian Period at 542 Ma. Subsequently, geologists did discover imprints of clearly quite complicated organisms in rocks a few tens of million years older than the start of the Cambrian. But these were flaccid, bag like creatures that recent research has shown to rely on filtering microorganisms from water or directly absorbing organic matter through their skin.



An Ediacaran animal (*Dickinsonia*)

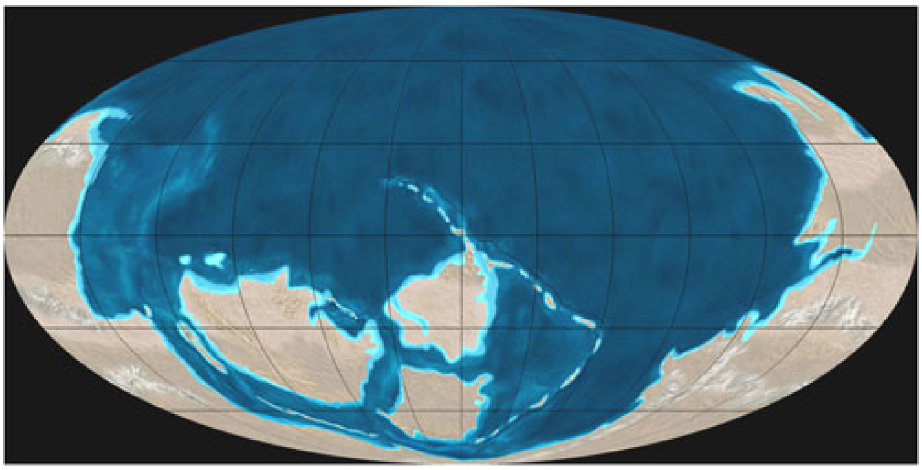
In many parts of the world the oldest Cambrian rests with profound unconformity on deformed Precambrian rocks. The lowest Cambrian rocks are often almost pure quartz sandstones. Many of the hills of North West Scotland have a gleaming white cap of Lower Cambrian quartzite above what has been termed the Great Unconformity where it occurs in Arizona's Grand Canyon. As a result, sedimentary sequences that continuously record the Precambrian to Cambrian transition and the biological explosion at the juncture are rare. But they show two curious features in sediments that immediately predate those bearing recognisable fossils: a complete lack of evidence for burrowing and millimetre-scale shell-like bodies made of calcium phosphate and carbonate, which are thought to have adorned the skins of otherwise unprotected animals.

Calcium, while a very common element is one of the most dangerous to life. Traces are essential for the signalling that goes on in cell metabolism, and too little snuffs out those vital processes. Yet too much – still a very low concentration in cell cytoplasm – results in the growth of minute mineral crystals within cells, also spelling cell death. This results from the limited solubility of calcium in water, compared with those of other common metals. At an early stage in evolution cells developed means of restricting the admission of calcium ions and efficient means of expelling excess amounts of calcium. The ubiquitous occurrence of Ca-rich marine limestones throughout the geological record bears witness to two things: the abundance of calcium ions in seawater; a closer look reveals that a great many limestones, going back some 3.5 billion years show traces of biomineralisation that helped form the limey sediments. In the second case, the calcium carbonate in most Precambrian limestones was secreted by photosynthetic blue-green bacteria in minutely thing layers, probably in the form of a slimy film excreted to avoid calcium toxicity. Palaeontologists have long suspected that the earliest skeletal materials formed by animals evolved from the need to excrete biomineralised films by turning a metabolic necessity into functional and integral parts of their body plans: arms and armour. Yet Precambrian limestones are not rare, so why the sudden adoption of waste products in this way?



Creatures from the Early Cambrian

A fairly old hypothesis is that calcium in seawater must have risen above a threshold that posed toxic threat to all living things and excretion had to increase to maintain the balance, perhaps matched with increasing sizes of animals in the late Precambrian. Only recently has support been found for this suggested evolutionary trigger, initially from analysis of brines trapped in crystalline materials within sediments, such as salt (NaCl). But the very presence of such halite in a sediment is a universally accepted sign of evaporation increasing ionic concentrations in isolated seawater lagoons, whereas a general increase in marine calcium would be needed to present sufficient chemical stress that the whole of animal evolution would require a step-change for survival. It turns out that support for the hypothesis stems from two isotopic systems most usually associated with dating the formation and weathering of continental crust: those of strontium and neodymium.



Continents at the start of the Cambrian (Credit: Ron Blakey)

The global record of the ratios $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ shows unusually large changes in the run-up to the Cambrian Period, the first rising to the highest level recorded in geological history and the second reaching a historic nadir during the Cambrian. This anti-correlation signifies the greatest chemical weathering of older continental crust in the history of the Earth (Peters, S. & Gaines, R.R. 2012. Formation of the 'Great Unconformity' as a trigger for the Cambrian explosion. *Nature*, v. **484**, p. 363-366; DOI: 10.1038/nature10969). Not only would this have poured dissolved ions, including those of calcium, into the oceans and raised their concentrations in seawater, but vast areas of the continents would have been eroded to form huge coastal plains, ripe for marine inundation. The last is exactly what the near-universal unconformity at the base of the Cambrian signifies. Presaging this long drawn-out grinding of continents to their gums had been a protracted bout of continental assembly to form the Rodinia supercontinent around 1000 Ma though collision and mountain building. Then Rodinia broke apart, its fragments being driven by plate tectonics to reassemble, along with vast chains of new crust formed in volcanic island arcs, by yet more orogenesis: tectonically high-energy times matched by the processes of denudation on land.

Related articles: Missing rocks may explain why life started playing shell games (arstechnica.com)

Burrowers: knowing front from back (*July 2012*)

In sedimentary rocks below the base of the Cambrian there is not only a dearth of body fossils, but signs of creatures burrowing and stirring up the sediment are most uncommon. A burrower needs several criteria to be fulfilled if it is to thrive: a supply of oxygen; sufficient food; a body able to penetrate sediment and an ability to move back and forth - though forth would probably do fine, provided the animal could turn corners. The amount of oxygen in sea-bottom water would have influenced its availability beneath the seabed. Whatever the conditions, dead organic matter falls and is buried by sediment before it is oxidised away, even nowadays. There is little sign that there was any marked change between the oxygenation of the planet just before and after the start of the Cambrian, so the main control over burrowing is that of animal morphology.

Many modern burrowing animals are pretty flaccid although moving sediment aside and upwards demands some muscle power. Most important, the creature needs a means of navigation, albeit of a rudimentary kind, and since what goes in beneath the surface – food – must go out – excreta. So there must be a front- and a back end. That 'fore-and-aft' symmetry is the essential feature of bilaterian animals. Only a limited range of animal taxa don't have that built-in symmetry. Sponges are the most obvious example, having no discernible symmetry of any kind. Radially symmetrical animals, such as jellyfish and coral polyps, only have a top and a bottom. An absence of inbuilt horizontal directionality stops non-bilaterians from burrowing in any shape or form. But, so what?

The vast majority of animals have some kind of bilateral symmetry; even echinoderms have it from their 5-fold symmetry that is also the simplest kind of radiality. By the start of the Cambrian, not only had bilaterians split off from the less symmetrical, but so too had almost all the phyla living today, and several that became extinct in the last 542 Ma. The only logical conclusion is that emergence of bilaterians and their fundamental diversification took place in the Precambrian: they are absent from earlier strata only because they had no hard parts. Comparing the DNA of living representatives of the main bilaterian phyla and with that of non-bilaterians can help date the times of genetic and morphological separation, but only crudely. This 'molecular clock' approach points to some time between 900 and 650 Ma ago for the last common ancestor of bilaterians.

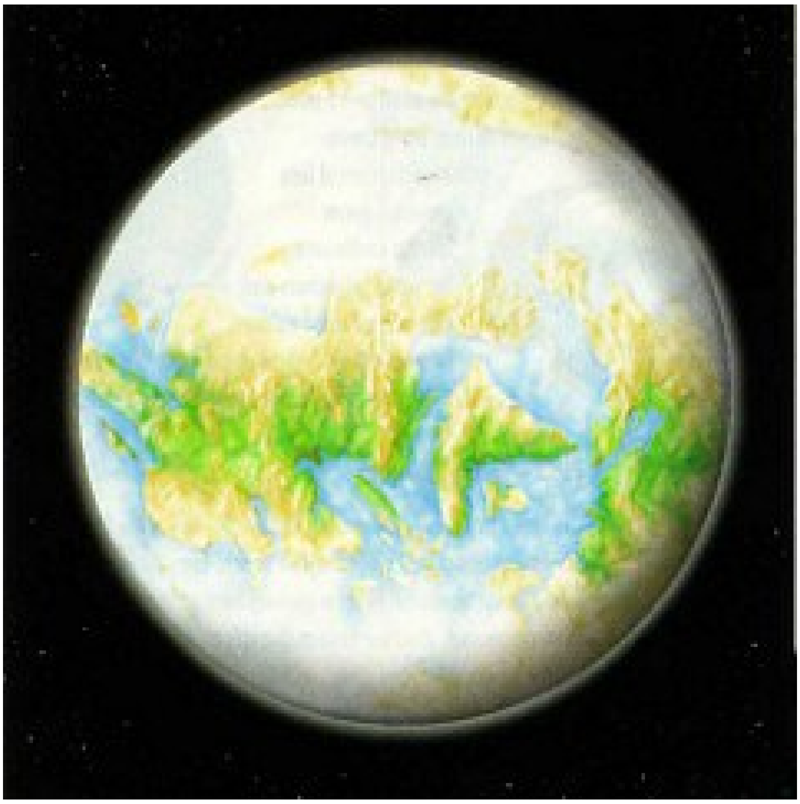
Uruguayan fossil burrows from late Neoproterozoic (Credit: Pecoits et al. 2012)

Getting a handle on the minimum time for the split depends either on finding fossils or unequivocal signs of bilaterian activity. The oldest unequivocally bilaterian fossils occur in rocks about 550 Ma old, which doesn't take us much further back than the base of the Cambrian. But there are trace fossils that are significantly more ancient (Pecoits, E. *et al*. 2012. Bilaterian burrows and grazing behaviour at >585 million years ago. *Science*, v. **336**, p. 1693-1696; DOI: 10.1126/science.1216295). They are tiny burrows in fine-grained sediments from Uruguay, so tiny that there is a chance that they may be traces of grazing on seabed bacterial films rather than beneath it. The decider is the mechanics of trace fossil formation. Surface tracks only a millimetre or so across would only penetrate the biofilm, so on lithification they would simply disappear. Burrows on the other hand penetrate the sediment itself to get at food items. Even if this was a biofilm, the track would be in sediment above the film, so compaction would preserve it. The Uruguayan examples are exquisite horizontal burrows, and they push back the minimum age for the origin of the bilaterians to at least 40 Ma older than the start of the Cambrian. In fact 585 Ma is a minimum age for the sediments as it is the U-Pb age of zircons in a granite that intrudes and metamorphoses them.

An equally significant observation is that the burrows appear towards the end of a glacial episode – probably the last of the Neoproterozoic 'Snowball Earth' events – as marked by tillites below the burrowed shales and occasional 'dropstones' in them. Could it be that the climatic and other stresses of a global glaciation triggered the fundamental division among the Animalia?

Early animals and Snowball Earth (*October 2012*)

Palaeobiologists generally believe that without a significant boost to oxygen levels in the oceans macroscopic eukaryotes, animals in particular, could not have evolved. Although the first signs of a rise in atmospheric oxygen enter the stratigraphic record some 2.4 billion years ago and eukaryote microfossils appeared at around 2 Ga, traces of bulky creatures suddenly show up much later at ~610 Ma with possible fossil bilaterian embryos preserved in 630 Ma old sediments. An intriguing feature of this Ediacaran fauna is that it appeared shortly after one of the Neoproterozoic global glaciations, the Marinoan 'Snowball' event: a coincidence or was there some connection? It has looked very like happenstance because few if any signs of a tangible post-Marinoan rise in environmental oxygen have been detected. Perhaps the sluggish two billion-year accumulation of free oxygen simply passed the threshold needed for metazoan metabolism. But there are other, proxy means of assessing the oxidation-reduction balance, one of which depends on trace metals whose chemistry hinges on their variable valency. The balance between soluble iron-2 and iron-3 that readily forms insoluble compounds is a model, although iron itself is so common in sediments that its concentration is not much of a guide. Molybdenum, vanadium and uranium, being quite rare, are more likely to chart subtle changes in the redox conditions under which marine sediments were deposited.



The Earth 640 Ma ago during the Marinoan 'Snowball' event (Credit: Cornell University)

Swapan Sahoo of the University of Nevada and colleagues from the USA, China and Canada detected a marked increase in the variability of Mo, V and U content of the basal black shales of the Doushantuo Formation of southern China, which contain the possible eukaryote embryos (Sahoo, S.K and 8 others 2012. Ocean oxygenation in the wake of the Marinoan glaciation. *Nature*, v. **489**, p. 546-549; DOI: 10.1038/nature11445). These rocks occur just above the last member of the Marinoan glacial to post-glacial sedimentary package and are around 632 Ma old. Since the black shales accumulated at depths well below those affected by surface waves that might have permitted local changes in the oxygen content of sea water the geochemistry of their formative environment ought not to have changed if global chemical conditions had been stable: the observed fluctuations may represent secular changes in global redox conditions. The earlier variability settles down to low levels towards the top of the analysed sequence, suggesting stabilised global chemistry.

What this might indicate is quite simple to work out. When the overall chemistry of the oceans is reducing Mo, V and U are more likely to enter sulfides in sediments, thereby forcing down their dissolved concentration in sea water. With a steady supply of those elements, probably by solution from basalt lavas at ocean ridges, sedimentary concentrations should stabilise at high levels in balance with low concentrations in solution. If seawater becomes more oxidising it holds more Mo, V and U in solution and sediment levels decline. So the high concentrations in sediments mark periods of global reducing conditions, whereas low values signal a more oxidising marine environment. Sahoo *et al*.'s observations suggest that marine geochemistry became unstable immediately after the Marinoan glaciation but settled to a fundamentally more oxidising state than it had been in earlier times, perhaps by tenfold increase in atmospheric oxygen content. So what might have caused this and the attendant potential for animals to get larger in the aftermath of the Snowball Earth event? One possibility is that the long period of glaciers' grinding down continental crust added nutrients to the oceans. Once warmed and lit by the sun they hosted huge blooms of single-celled phytoplankton whose photosynthesis became an oxygen factory and whose burial in pervasive reducing conditions on the sea bed formed a permanent repository of organic carbon. The outcome an at-first hesitant oxygenation of the planet and then a permanent fixture opening a window of opportunity for the Ediacarans and ultimately life as we know it.

Related articles

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The Ediacaran fossils: a big surprise (*December 2012*)

The first macroscopic life forms were the enigmatic bag-like and quilted fossils in sedimentary rocks dating back to 635 Ma in Australia, eastern Canada and NW Europe. They are grouped as the Ediacaran Fauna named after the Ediacara Hills in South Australia where they are most common and diverse. Generally they are not body fossils but impressions of soft-bodied organisms, often in sandstones rather than muds. Some are believed to be animals that absorbed nutrients through their skin, whereas others are subjects of speculation. One thing seems clear; these first metazoans arose because of some kind of trigger provided by the global glacial conditions that preceded their appearance (s *Early animals and Snowball Earth* above). It has always been assumed that, whatever they were, Ediacaran organisms lived on the sea floor, probably in shallow water. New sedimentological evidence found in the type locality by Gregory Retallack of the University of Oregon seems set to force a complete rethink about these hugely important life forms (Retallack, G.J 2012. Ediacaran life on land. *Nature*, v. **493**, p. 89-92; DOI: 10.1038/nature11777). So momentous are his conclusions that they form the subject of a *Nature* editorial in the 13 December 2012 issue of *Nature*.

Retallack, a specialist on ancient soils of the Precambrian, examined reddish facies of the Ediacara Member of the Rawnsley Quartzite of South Australia, whose previous interpretation have a somewhat odd background. Originally regarded as non-marine, before their fossils were discovered, when traces of jellyfish-like organisms turned up this view was reversed to marine, the red coloration being ascribed to deep Cretaceous weathering. A range of features, such as clasts of red facies in grey Ediacaran rocks, the presence of feldspar in the red facies – unlikely to have survived deep weathering – bedding surfaces with textures very like those formed by subaerial biofilms, and desiccation cracks, suggest to Retallack that the red facies represents palaeosols in the sedimentary sequence. Moreover, some features indicate a land surface prone to freezing from time to time. The key observation is that this facies contains Ediacaran trace fossils representing many of the forms previously regarded as marine animals of some kind, including *Spriggina*, *Dickinsonia* and *Charnia* on which most palaeontologists would bet good money that they were animals, albeit enigmatic ones.

Specimen of Edicaran *Spriggina* (credit: Wikipedia)

If Retallack's sedimentological observations are confirmed then organisms found in the palaeosols cannot have been animals – what could they have eaten? – but perhaps akin to lichens or colonial microbes, and survived freezing conditions. As they occur in other facies more likely to be subaqueous, then they were 'at home' in a variety of ecosystems. As the *Nature* editorial reminds us, from the near-certainty that early macroscopic life was marine there is a chance that views will have to revert to a terrestrial emergence first suggested in the 1950s by Jane Grey. Uncomfortable times lie ahead for the palaeontological world.

Related articles: Controversial claim puts life on land 65 million years early (nature.com); Were Weirdo Ediacarans Really Lichens, Fungi, and Slime Molds? (blogs.scientificamerican.com)