The chemical conditions for life (January 2003)

Robert Williams (Oxford University) and João Fraústo da Silva (Technical University of Lisbon) have an unconventional, but plausible take on the conditions for life’s origin and evolution (Williams, R.J.P & Fraústo da Silva J.J.R. 2003. Evolution was chemically constrained. *Journal of Theoretical Biology*, v. 220, p. 323-343; doi: 10.1006/jtbi.2003.3152). However life began, presumably as cytoplasm containing DNA, RNA and proteins within a semi-permeable wall, it was surrounded by the chemistry of whatever environment it appeared in. The proto-cell would have drawn hydrogen ions from water, to perform the proton pumping that is essential to all living organisms, and thereby created more oxidising conditions in its immediate vicinity. Oxidation would have generated nitrogen from ammonia, released metals from their sulphides and converted other sulphides to sulphates. Conversely, ions in its surroundings would have been able to “leak” into the cell itself. By creating oxidised radicals, this inward leakage would have rebounded the cell’s activity on itself, with potentially toxic consequences. Survival depended on two things: exploiting the opportunities, such as nitrogen fixation, using oxygen and even photosynthetic chemistry; and fending off potential toxic shock. One of the most interesting aspects is the role assumed by calcium ions. Their presence inside a cell would have precipitated DNA, by binding to it, with fatal consequences. The upshot, according to Williams and Fraústo da Silva, is the special role of calcium as a messenger ion, perhaps having arisen through the necessity to pump it out again. Today, the range of calcium concentrations in cells is extremely limited, too much or too little being fatal. Perhaps a sudden change in the calcium-ion concentration in seawater in the late Neoproterozoic was responsible for the extreme excursions in carbon isotopes that are ascribed to mass extinction and equally massive adaptive radiations. My own stab in the dark, is that a protective response to calcium stress by metazoans at that time may explain the sudden appearance of calcium-rich hard parts, which we know as the Cambrian Explosion. They evolved means of excreting calcium from their many cells, so creating an outer “shell” that eventually developed into either “armour” or “armament”.

The delightful aspect of Williams and Fraústo da Silva’s ideas is that they break from pure genetic determinism and the dominance of pure chance in addressing the central issue in the whole of science - the complete interconnectedness of real nature. What they discuss is epigenetic influences on evolution.


The Early Cretaceous *lagerstätten* of NE China (February 2003)

Barely a month passes without some weird fossil emerging from the widespread excavations in Early Cretaceous lacustrine sediments of north-east China. It is probably the most productive palaeontological formation in the world, and has shed light on more than just the dinosaurian origin of birds, and drives ideas on the rise of angiosperm plants and early mammals. As well as abundant fossils, the *lagerstätten* formed under low-oxygen
conditions and preserves exquisite detail of soft tissue. A review of the material and the environment in which it formed is welcomed by all palaeontologists (Zhou, Z, Barrett, P.M. & Hilton, J. 2003. *An exceptionally preserved Lower Cretaceous ecosystem*. *Nature*, v. 421, p. 807-814; DOI: 10.1038/nature01420). Zhou *et al.* discuss the formation from two angles. Scientifically their focus is on the potential for building a complete ecosystem for the area during the Early Cretaceous. However, they also record the massive problems that result from haphazard collection by organised teams of locals and fossil dealers – incidentally the source of the infamous *Archaeoraptor* forgery (see “Piltdown” bird March 2001). Their review is also a plea for some kind of firm regulation of collection, although experience from many other *lagerstätten* suggests that is unlikely in the short-term.

**Did terrestrial life emerge later than geochemists think? (February 2003)**

A lot hangs on the notion that life can make it from abiogenic chemistry very quickly once a world has watery seas. Evidence from oxygen isotopes in the oldest known terrestrial zircons suggests that liquid water was around on Earth by about 4400 Ma (see *Pushing back the “vestige of a beginning”* Planetary Science February 2001, and *The Hadean was cool* Climate change June 2002). It lies behind the search for signs of life on Mars and the fiasco surrounding the premature announcement of bacterial fossils in a meteorite reputedly from the Red Planet. Right here, controversy has been raging over the once-living status of tiny patterns in 3500 Ma cherts from Western Australia (see *Doubt cast on earliest bacterial fossils* April 2002), and on the true significance of isotopically light carbon trapped in apatite crystals in the 3800 ma Akilia metasediments of West Greenland. Both have been claimed as signs of early, well-organised life, but the evidence is circumstantial.

Investigative journalism is very welcome in science, mainly because most scientists are either too polite, or grumble quietly in the coffee room. Jon Copley, who teaches at Southampton University, has ventured into the field by interviewing some of the main antagonists in the “Is this a sign of life” debate (Copley, J. 2003. *Proof of life*. *New Scientist*, 22 February 2003, p. 28-31). His article is most revealing, by getting down to brass tacks. There is a lazy tendency in science to invoke William of Ockham’s “Razor”, i.e. that the simplest explanation of data is the best. That is fine for the Old Bailey, in the manner of Roman legal argument of *cui bono* (who benefits?), but the natural world has a cussed tendency to pay no attention to human linear thought. It is not a place for “elegance”, no matter how much scientists feel in awe of elegant mathematical proofs. That it is wielded in favour of the most complex process in the universe to account for geochemical and other data is a bit odd. Central to Copley’s sharp journalism lies something of which C-isotope specialists do not speak much. At temperatures around 400ºC and a few hundred times atmospheric pressure can result in carbon monoxide and hydrogen combining to form hydrocarbons. Fischer-Tropsch synthesis of hydrocarbons that fuelled Nazi Germany and South Africa under apartheid does occur in nature. The ideal place is around deep-sea hydrothermal vents. The reactions favour $^{12}\text{C}$ over the heavier $^{13}\text{C}$ and results in $\delta^{13}\text{C}$ just as negative as do living processes. Isotopically light carbon in rocks that do not contain cast iron confirmation through tiny fossils, cannot be seen as proof that life existed. Probably the oldest irrefutable fossils are of bacteria in the 1900 Ma Gunflint Chert of Ontario. If we cannot be sure that C-isotopes help detect living processes on the early Earth, then results from missions, such as Beagle-2, to Mars could be exercises in futility.
**Flying feathers (March 2003)**

Steadily, the remarkable fossil record in Cretaceous terrestrial sediments in China is revolutionising ideas about vertebrate evolution, particularly among small dinosaurs and early birds (see *The Early Cretaceous* lagerstätten of *NE China* above). The long-held view that birds simply emerged fully fledged and flying from the dinosaurs has had to be thoroughly amplified. The sheer diversity, combined with intricate preservation in the Chinese sediments reveals feathering on a host of animals that are not birds, but earlier, bipedal dinosaurs. Some may have flown, but others had feathers for some other reason. Feathers are not a prerequisite for flying, and are so odd and complex in morphology and growth, that it has always been probable that they emerged and evolved over a long period preceding the appearance of true birds. Now it is possible to begin dissecting that strange evolutionary divergence, and Richard Prum and Alan Brush of the Universities of Kansas and Connecticut combine information about feathers and discussion of new fossils in a superbly illustrated review in the March issue of *Scientific American* (Prum, R.O. & Brush, A.H. 2003. Which came first, the feather or the bird. *Scientific American*, March 2003, p. 60-69).

**Squirrels and tectonics (March 2003)**

The squirrel family (Sciuridae) is one of the most widespread groups of mammals, only Australia, the Pacific islands and Antarctica being squirrel-free. The main reason is that squirrels are a primitive group among the rodents, themselves accounting for almost 50% of all living mammals species. The earliest fossil squirrel (*Douglassciurus jeffersoni*) was found in Late Eocene sediments in western North America, and the family seems to have originated there. The present wide distribution of squirrels bears witness to the many opportunities for migration in the Palaeogene, when continental masses were much less dispersed than they are today, together with changing environmental conditions that would have acted to drive migration. In the same way as human migrations have been charted and timed using genetic sequencing and molecular clock hypotheses, this unique group has been studied in detail (Mercer, J.M. & Roth, L. 2003. *The effects of Cenozoic global change on squirrel phylogeny*. *Science*, v. 299, p. 1568-1572; DOI: 10.1126/science.1079705). The general picture outlined by Mercer and Roth is that the Sciuridae migrated first across Beringia to reach Asia, then Europe and eventually Africa. In terms of migration rates, this was fast, the earliest European squirrel (*Palaeosciurus*) occurring in Early Oligocene sediments – this is also the earliest representative of squirrels that bear signs of the distinctive chewing muscles whose use today delights us all. Near identical musculature is found in the Red Squirrel and many other tree squirrels (*Sciurus sp.*), and their “living fossil” anatomy is borne out genetically.

As well as giving a fascinating insight into how modern genetic techniques help organise the cladistics of animals, the paper is full of information about the sheer diversity that this lowly group has achieved in about 50 Ma. Ground squirrels, rock squirrels, marmots, and tree squirrels abound, but none are so fascinating as the flying squirrels. Their teeth are similar to those in early Oligocene fossils, and genetic analysis suggests a common ancestry relatively early in squirrel evolution and migration. However, fossils of flying squirrels, in the areas where they are found today (North America and Asia) appear quite late in the stratigraphic column. The authors suggest that perhaps flying ability arose several times
independently, based on a labile trait in the genes of their clade. There is also evidence for population “bottlenecks” that preceded adaptive radiation in several area. For instance, the entire radiation of South American squirrels seems to have stemmed from a single lineage that crossed the Isthmus of Panama shortly after it formed in Pliocene times. African squirrels can be accounted for by just two colonisations in the Miocene, and those of Indonesian archipelago east of the Wallace Line by migration during the Late Miocene, when sea-level was at its lowest before the Pleistocene lowstands. Most astonishing of all, is the Giant Squirrel of Borneo (Rheithosciurus), which is genetically closest to the squirrels of North America rather than its more diminutive cousins in the Sunda Shelf islands – did its ancestors move with astonishing speed, or did all related squirrels along its migration route become extinct quite rapidly?

Note added 1 April 2003: A possible answer to the origin of the Giant Squirrel of Borneo lies in a collection made recently from a unique lagerstätten in a clay-filled pocket within laterites of northern Karnataka in India. The discoverer, Dr P.U. Siffli of Sringeri Institute of Palaeontology, has posted provisional results on his web site (http://geocities.yahoo.com/pusiffli/squirrels.html). The range of fossil rodents from near Sringeri is astonishing. Among them are bones of an undoubtedly primitive squirrel of enormous dimensions – approximately the size of a large child. Its masticatory musculature is similar to that of the North American Douglassciurus jeffersoni of Eocene age, i.e. unlike that of modern tree-squirrels. The biggest surprise lies in the dentition of the Sringeri giant squirrel. The typical rodent second incisors are serrated and arranged in a similar way to the shearing canines of mammalian carnivores. Its back teeth bear close resemblance to carnivore carnassials. As if this was not sufficient, the body cavity of the best preserved fossil contains pellets made up exclusively of bones from primitive hamsters, which abound in the lagerstätten. In a personal communication, Pandit Unmer makes a convincing case that he has discovered the only known predatory squirrel (provisionally named Titanosciurus sringeriensis), and will soon submit his finding for peer review. His only regret is that establishing a stratigraphic age for the laterite-bound pocket is proving to be very difficult. Sitting atop Archaean gneisses, the laterite can be correlated with similar palaeosols that cover the 64 Ma Deccan flood basalts some 130 km to the north, yet they defy dating by radiometric means. Dr Siffli would welcome offers to date the Sringeri lagerstätten (pusiffli@yahoo.com)

Homing in on the great end-Permian extinction (April 2003)

Discussing what actually killed off around 95% of all species 251 Ma ago has become the perennial mass-extinction topic, now that the K-T boundary event is more or less done and dusted, bar a little murmuring over the Deccan Trap. Michael Benton of the University of Bristol has summarised the current state of play for the Permian-Triassic (P-Tr) event (Benton, M. 2003. Wipeout. New Scientist, 26 April 2003, p. 38-41). Despite many attempts to link an impact to the annihilation – such evidence as there is (see Buckyballs and the end-Palaeozoic extinction, February 2001) has not been reproduced by independent analysis of the material. Weighty evidence comes instead for an Earth-induced event, from the coincidence of the monstrous Siberian Traps with the 100 thousand years or less that the extinction occupied, and from complete sequences across the P-Tr boundary in a Japanese ophiolite and a shallow marine section at Meishan in South China. As well as an intricate series of faunal changes, the Meishan sequence has now provided a complete
record of oxygen and carbon isotopes that span the boundary event. The oxygen data suggest a 6ºC rise in global temperature at exactly the stratigraphic level of the extinction and of a massive lurch towards light carbon. Such a high proportion of 12C occurs at the boundary that it cannot have been induced by sterilisation of the oceans, which may well have happened as a result of the extinctions. Nor can even the huge belch of mantle CO2 emitted by Siberian continental flood basalts. The two combined only account for 40% of the carbon-isotope excursion. Release of methane from long-term storage as gas hydrate on the Permian sea floor is the only conceivable candidate. So it looks as if a runaway “greenhouse”, plus toxic gas and maybe acid rain put paid to most living things. Such a wiping out left lifeless oxygen-poor oceans – originally dubbed “Strangelove oceans” by Ken Hsu after the eponymous insane doctor. Triassic times did not see explosive reoccupation of abandoned niches, recovery taking up to 50 Ma from a tiny population of not very diverse organism. Benton has written a book on the P-Tr event (When Life Nearly Died, Thames & Hudson), and that is likely to be a rattling read. New Scientist maintains it’s irritating habit of never referring to sources in its articles, so to go further, you will have to buy the book.

Microbes showed no sign of change following a “Snowball Earth”

The “Snowball Earth” hypothesis has suffered quite a lot since its original promotion (see: Meltdown for Snowball Earth?, February 2002; Snowball Earth hypothesis challenged, again, December 2002). Whatever the eventual fate of the notion that the entire Earth was iced over from pole to pole, the fact that glaciers reached sea level at low latitudes at least twice in the Neoproterozoic seems to be an established fact. Such climate swings must surely have had an effect on life, either by driving up the rates of extinction and adaptive radiation because of stress, or perhaps providing nutrients to the oceans in vast amounts that allowed the phytoplankton base of the food chain to explode (see: The Malnourished Earth hypothesis - evolutionary stasis in the mid-Proterozoic, September 2002). One of the first discoveries of low-latitude glaciogenic deposits was around Death Valley, California by the late Preston Cloud, who worked there during the 1960s. So it is fitting that palaeobiologists associated with the Preston Cloud Research Laboratory at the University of California, Santa Barbara have dissected sediments within and immediately beneath the 750 Ma diamictites that Cloud interpreted as glacial in origin, to test for signs of evolutionary change (Corsetti, F.A., Awramik, S.M. & Pierce, D. 2003. A complex microbiota from snowball Earth times: Microfossils from the Neoproterozoic Kingston Peak Formation, Death Valley, USA. Proceedings of the National Academy of Science, v. 100, p. 4399-4404; doi: 10.1073/pnas.0730560100). In cherts within carbonate units they found a surprisingly diverse range of undoubted microfossils, that are probably auto- and heterotrophic Eucarya, but no difference between pre-glacial and glacial levels, in terms of their biota. Although this single piece of work does not prove that there was no biological change associated with a major cooling during the Neoproterozoic, it does cast doubt on the severity of its effects on life. Most important, the study shows that well-preserved cellular material is available for study in sediments that occur with glaciogenic diamictites, and should open up a new line of research bearing on the rise of the metazoan (multi-celled) Eucarya, which appeared in large numbers shortly after the last (~600 Ma) glacial epoch. Most if not all Neoproterozoic carbonates, whose universal presence in close stratigraphic proximity to glaciogenic strata first hinted at low-latitude frigidity, contain abundant chert nodules that are the best preserving medium for delicate and tiny cell structures.
Extinction at the Precambrian-Cambrian boundary (May 2003)

The very beginning of the Cambrian is associated in every geologist’s mind with the explosive appearance and diversification of animals with hard parts. Why this dramatic introduction to the modern biological world occurred is one of the great questions in evolution. Some connection with the effects of “Snowball Earth” events in the late Neoproterozoic was thrown into doubt by evidence that it had little effect on micro-organisms (see *Microbes showed no sign of change following a “Snowball Earth”* above). Exactly at the boundary there is a marked fall in the abundance of carbon-13, and this negative $\delta^{13}$C excursion is so widespread that it is the best indicator of the position of the Precambrian-Cambrian boundary in stratigraphic sequences of roughly this age. One of the places that it occurs is in Oman, reported previously (*A possible fuse for the Cambrian Explosion* above). The paper describing the evidence from Oman that the carbon-isotope excursion relates to a mass extinction is now out (Amthor, J.E. and 6 others 2003. Extinction of *Cloudinia* and *Namacalathus* at the Precambrian-Cambrian boundary in Oman. *Geology*, v. 31, p. 431-434). The disappearance of the distinctive eukaryote fossils coincides exactly with the carbon anomaly. Luckily, so too does a volcanic ash horizon from which zircons provide a very precise U-Pb age of 542±0.3 Ma. This matches less precise dates for the anomaly from Siberia and Namibia, and seems likely to become accepted as the definitive age for the start of the Phanerozoic.

“Snowball Earth” and evolutionary diversification: Australians speak out (May 2003)

By comparison with the vast amounts of Australian diamictites that span a range of Neoproterozoic ages, the sites elsewhere, from which evidence in support of the “Snowball Earth” hypothesis and possible effects on evolution have been drawn, are puny. Besides that, the Late Precambrian of Australia has the best record of biological change, including the type locality for the Ediacaran fauna that presaged the Cambrian Explosion. Although somewhat less hasty than the flurry of papers on the “Snowball” hypothesis, since 1998, the appearance of published data from the “Red Continent” is sure to push the debate decisively one way or another. Palaeontologists from the Geological Survey of Western Australia, Macquarie University and Mineral Resources Tasmania have just unveiled details of acritarchs from late-Neoproterozoic sediments that overlie the Marinoan (~600 Ma) glaciogenic rocks in South Australia (Grey, K. *et al*. 2003. Neoproterozoic biotic diversification: Snowball Earth or aftermath of the Acraman impact? *Geology*, v. 31, p. 459-462; DOI: 10.1130/0091-7613(2003)031<0459:NBDSEO>2.0.CO;2). Acritarchs are spore-like fossils, that probably represent encysting algae. Their rapid diversification makes them useful biostratigraphic indicators from the Late Precambrian to the present. Grey *et al*. Found that the same assemblage of acritarchs occur before the Marinoan glaciogenic strata and after the succeeding “cap” carbonate. They are part of a group that can be traced back to the Mesoproterozoic. However, higher in the sequence that they examined there is a distinctive layer of debris that contains evidence of impact-induced shock. This can be correlated with little doubt to the 90 km Acraman structure in South Australia, which formed at 580 Ma with an energy likely to have had a major influence on life. Sure enough, in the strata above this ejecta layer a completely new type of acritarch group appears and diversifies rapidly, while the pre-impact groups simply disappear. Clearly, the Acraman
impact is implicated in this sudden biological change; an extinction followed by rapid diversification. Acritarchs are thought to represent the phytoplanktonic base of the Neoproterozoic food chain. Immediately above the strata in which the post-impact acritarchs diversified lie sandstones that contain the famous Ediacara fauna of the first large, soft bodied animals. The Marinoan “Snowball” event seems disconnected from this evolutionary leap.

**Middle Devonian extinction and impactite layer (June 2003)**

Around 380 Ma there was a major extinction event (~40% of marine animals) that is recorded world-wide, along with negative shifts in $^{13}$C. As with other extinctions since the discovery that the Chixculub crater was exactly the same age as the famous K/T extinction, there has been a quest to link this Middle Devonian event to an extraterrestrial cause. Now there seems to be a positive result (Ellwood, B.B. and 4 others 2003. *Impact eject layer from the mid-Devonian: possible connection to global mass extinctions*. *Science*, v. 300, p. 1734-1737; DOI: 10.1126/science.1081544). A Devonian section in Morocco contains a thin layer rich in shocked quartz, microspherules of devitrified glass, and metals, that also has low $\delta^{13}$C. The carbon-isotope shift could have resulted from either of two possible consequences: collapse of the marine ecosystem; or massive release of methane from gas hydrates destabilised by the impact. Only one crater coincides with the date of the layer and the extinction, Kaluga in Russia, but it is only 15 km wide, so cannot have had any dramatic biological effect. However, the very presence of a moderate crater at exactly the right age might signify other impacts, because it is becoming increasing clear that impacts come in clusters, perhaps because large, approaching bodies break up before they hit the Earth.

**Setting the fossil record to rights (July 2003)**

Much has been made of ups and downs in the diversity of life from the global fossil record of the Phanerzoic, including the possibility of massive downturns in diversity related to a variety of cause for mass extinction. However, there are many biases in what is an inevitably imperfect record of biodiversity. There are anthropogenic influences, for a start. Although they are becoming more adventurous, palaeontologists cut their teeth on sites close to home, and most of them live in the richer parts of the world. Insatiable demand for fossils, but mainly of the spectacular and valuable kinds, has grown a world-wide industry of commercial fossil mining. That may homogenise the geographic coverage of the fossil record, but it is very tempting to go for the richest troves and ignore meagre pickings. Sedimentation is by no means guaranteed to have been constant through time, partly because of ups and downs of sea level and changes in the pace of erosion of earlier rocks. Although Phanerzoic stratigraphy seems complete when sections from all over are pieced together, in any one place there are huge gaps of erosion or non-deposition. It is very easy to come upon several beds of sedimentary rock and conclude that the sequence represents a continuum in time. Not so, as any examination of such beds forming today often reveals that intact preservation is the exception compared with erosion and reworking. The global areas of exposed rocks that cover, say, 10 Ma chunks of Earth history is by no means constant either. Another factor that conspires to cast doubt on the veracity of the existing fossil record is that the numbers of possible ecological niches that once existed in different tectonic environments are probably not the same. Active oceanic arcs have few such
niches, whereas tropical zones of shallow shelves have vastly more. There are lots more uncertainties, and New Zealand palaeontologists have painstakingly tried to develop some means of allowing for them in the Tertiary record of their islands (Crampton, J.S. et al. 2003. Estimating the rock volume bias in paleodiversity studies. Science, v. 301, p. 358-360; DOI: 10.1126/science.1085075). The simplest premise for estimating bias in the numbers of taxa preserved in rocks covering a particular time range is the available volume of rock from the period that can be sampled. One approach is to see how geologists have divided up that period in terms of distinct rock formations, the other just uses estimates of the areas underlain by sedimentary rocks laid down during the period. The first suggests that collecting should be systematically from formation to formation up a sequence, while the second implies that random grid sampling is the best approach. The New Zealand data suggest that the area approach is most appropriate there, largely because the local rocks formed in a sedimentologically simple, active-margin environment. Both methods seem to work in tectonically stable areas. This is just a beginning, but is raises the issue of how much weight can be placed on existing fossil collections in pondering on both titanic and slow-but-sure episodes in the last 544 Ma.

On the same tack, attempts are underway to correct the entire fossil record from 30 thousand collections, using a similar approach to sampling bias. John Alroy at the University of California, Santa Barbara has helped set up the Paleobiology Database following prompting by the most prolific fossil cataloguer, Jack Sepkoski, shortly before his untimely death in 1999. The web site allows anyone to generate diversity curves, but the process is a little complicated and best tackled by experienced palaeontologists. You can also enter information from your own collections. Early results are conflicting. Sepkoski’s original suggestion that diversity among marine faunas increased since the Triassic may be an artefact of the intensity of sampling which varies from age to age. However, using just molluscs seems to confirm that at least they did indeed radiate tremendously as Sepkoski had concluded (Schiermeier, Q. 2003. Setting the record straight. Nature, v. 424, p. 482-483; DOI: 10.1038/424482a).

Origins of the vertebrates (July 2003)

Long before techniques were developed to investigate the genetic stuff of living organisms, and when the only known repository of primitive, soft-bodied animals was the Burgess Shale, basic anatomical analysis suggested that maybe the ancestors of vertebrates were worms, sea squirts and even echinoderms. When the Burgess Shale fauna was re-evaluated and extended in the 1970’s by, among others, Simon Conway Morris of Cambridge University, it became clear that the fossil record was missing a great many delicate and sometimes very odd organisms. Entirely unsuspected phylla numbered among the occupants of that famous lagerstätte (site of exceptional preservation), but little new about our own ultimate origins. (Note added July 2003: It is now accepted that the Burgess Shale has revealed no hitherto undocumented phyla)

Vertebrates, echinoderms, sea squirts and a diverse collection of worm-like animals have one thing in common, though apparently very little else. The first opening to emerge during embryonic development is the anus, whereas in the rest of the animals (protostomes) it becomes a mouth. So, in the “supergroup” to which we belong, mouths appear at a later developmental stage; hence the sack-name “deuterostome”. This oddly dichotomous
embryonic unfolding points to a very early division among the animals, that might only be unveiled by discovery of even earlier lagerstätten than the Late Cambrian Burgess Shale. So far, no such source of palaeontological richness has been discovered in late Precambrian sedimentary rocks – crude “molecular clock” approaches to genetic divergence suggest that a great deal went on before the Cambrian Explosion at 544 Ma. However, the fossil-rich Cambrian of China does push back the record of delicate animals almost to that time. The recently discovered lagerstätte of Chengjiang is about 530 Ma old, and, as Conway Morris and his Chinese colleagues have discovered, it is rich in fossil deuterostomes. One group, the vetulicolians, bears a remarkable resemblance to what the pioneer vertebrate palaeontologist, Alfred Romer, suggested as a probable vertebrate ancestor – something with a front end bearing gill slits and a long, segmented tail. The Chengjiang deposit also contains jawless fish, together with unique “almost fish” called yunnanozoans that may be intermediate links between vetulicolians and fish. Similarly, there are intriguing hints that vetulicolians evolved towards the most primitive echinoderms, with bilateral symmetry rather than the fivefold form that emerged later. Clearly, the Chengjiang fauna was extremely diverse and therefore had a long evolutionary history. Since even more delicate, entirely soft-bodied Ediacaran animals were preserved as imprints in sandstones from the Late Neoproterozoic, it is maybe only a matter of time before low-energy lagerstätten are found from that time. There are abundant undeformed mudstones from that period throughout the world, but only painstaking rock splitting will find such treasures, unlike the large, “trip-over” Ediacaran trace fossils.


Iron and nickel in life’s origins (August 2003)

The crucial step in assembling amino acids into the proteins that are central to living organisms is the formation of peptide bonds. Amino acids are found even in meteorites and seem to form abiogenically with some ease. Peptide bonds link simple amino acids into long chains that are the essence of complex proteins, but this does not happen spontaneously. The bonds form in the presence of carbon monoxide, but require some kind of catalysis. Researchers at the University of Munich, Germany have discovered that very fine-grained precipitates of iron and nickel sulphides readily perform such catalytic functions (Huber, C. et al. 2003. A possible primordial peptide cycle. Science, v. 301, p. 938-940; DOI: 10.1126/science.1086501 ). This tallies nicely with one of the co-workers’ (Günter Wächtershäuser) hypothesis for the chemoautotrophic origin of life near sea-floor hydrothermal vents, where Fe, Ni and S are abundant, as is CO in the hot water that emanates from them.

Another K-T row (September 2003)

Since the discovery of the buried Chicxulub impact crater off the Yucatán Peninsula, Mexico, many geologists have regarded it as the “smoking gun” for the end-Cretaceous mass extinction. Such is the heft of K-T studies that money has been raised to drill into the crater and its overlying sediments. That began in late 2001 at an onshore site on the flank of the structure, and results are starting to emerge. However, research has been slow in getting
underway on the crucial part of the core that goes through the boundary itself. That section was taken from the project’s headquarters in Mexico City to the Free University of Amsterdam, by Jan Smit, one of the pioneers of K-T boundary studies. Samples began to reach other researchers in December 2002, 6 months after the boundary section arrived in Amsterdam. For many, this was a little too slow and suspicions have been raised. Everyone wanted to get abstracts into the AGU/EGS/EUG bun fight in Nice in April 2003, where a conference session on Chicxulub had been scheduled. One report presented there seems set to stun the pro-impact school. Gerta Keller of Princeton University studied foraminifera in the samples immediately above the impact breccia – there were plenty. She claimed that they represented a period of about 300 thousand years of sedimentation that followed the impact. Moreover, they occurred below the level of a thin glauconite-rich horizon, which seems to represent the K-T extinction event itself. Not surprisingly, Keller concluded that the impact could not have caused the extinction. Smit dismisses the allegation of “hogging” the core samples, and also suggests that the foram-rich layers represent sediment that was washed back into the crater soon after it formed. It has always struck me as odd that whenever something startling emerges from scientific research, a sort of preciousness overwhelms supposed scientific “objectivity”. Counter claims and new variants of ideas rapidly evolve on the periphery of the discovery. There are reputations to be built, and defended, and of course “sexy” themes attract cash. The initial work that led to the recognition of a global layer of mass destruction, carried out by the Alvarez father and son team in the late 1970s, was a purer form of science – driven by curiosity and little else.


Gamma-ray bursts and mass extinctions (September 2003)

There is a saying attributed to J.L. Austin which goes: “There are more ways of killing a cat than drowning it in butter”. It seems to apply to mass extinctions. A team of astrophysicists and palaeontologists from the University of Kansas and NASA, headed by Adrian Melott of the University of Kansas (Melott, A. et al. 2003. Did a gamma-ray burst initiate the late Ordovician mass extinction? arXIV:astro-Ph/0309415; DOI: 10.1017/S1473550404001910) has found peculiarities in the trilobite record after the Late Ordovician mass extinction (443 Ma) that are difficult to explain by the usual culprits. Planktonic trilobites were decimated, but those living in deeper water largely came through the extinction. Graptolites too incurred major changes, only the monograptids surviving until the Silurian. Many palaeontologists link the end-Ordovician extinctions to global cooling, evidenced by glacial rocks mainly in Africa. Melott and colleagues suggest that a realistic reason for a depth-related extinction pattern could be due to intense gamma rays emitted by the collapse of a nearby giant star into a black hole. Although most would be blocked by the Earth’s atmosphere, that would be at the expense of nitrogen oxides being created in large volumes from oxygen and nitrogen molecules. Nitrogen dioxide, the yellow colorant in photochemical smog would prevent solar radiation reaching the surface and trigger cooling. Also acid rain would lower the pH of surface water. Such a process could also explain the Late Ordovician glaciation of Africa.
Fossil oddities – a golfing trilobite and the ox-sized rodent (September 2003)

Gamblers and golfers do not like distractions, and many wear eye shades of some design or other. So it is intriguing to learn that a Devonian trilobite, *Erbenochile*, found in Morocco evolved a similar device. Richard Fortey and Brian Chatterton, of the British Museum of Natural History and the University of Alberta, respectively, analysed the peculiar eyes of this phacopid trilobite, and found that their tops had a sort of rim. Light shining down on the beast put the compound facets in shadow (Fortey, R. & Chatterton, B. 2003. *A Devonian trilobite with an eyeshade*. *Science*, v. 301, p. 1689; DOI: 10.1126/science.1088713). Not only would this arthropod have been undistracted from its activities by goings on above, but it could also see over its back.

Erbenochile erbeni – the Devonian trilobite with an eye shade from Morocco (Credit: Fortey & Chatterton 2003; Fig. 1)

Not since the discovery of the Late Miocene *Bullockornis* in Australia (see *The Ducks of Death* June 2000) have Neogene palaeontologists come up with a record beater. But now they have (Sanches-Villagra, M.R. et al. 2003. *The anatomy of the world’s largest extinct rodent*. *Science*, v. 301, p. 1708-1710; DOI: 10.1126/science.1089332). The Late Miocene of Venezuela has yielded a rodent (*Phoberomys*), whose bones suggest that it weighed in at about 0.7 tonnes. It is related to modern guinea pigs, and probably had much the same herbivorous habits. Its teeth suggest that it was grazer too, and like the modern capybara (one tenth the size of *Phoberomys*) it lived in swamps. Rodents now rank as the mammalian order with the greatest range of sizes. Because the digestive systems of mammals cannot efficiently break down the high cellulose content of grasses without the aid of internal bacteria, the bigger their gut, the more efficient they are as herbivores. So giant rodents make sense as regards their metabolism. However, they are not as well known for galloping as many other grazers, which is why smaller rodents prefer to escape predation by diving.
into burrows or among boulders. That would be difficult for a creature as big as an ox. Swamp dwellers, like the capybara and *Phoberomys*, can get away with not being fleet of foot, but would not do well on open grassland. Like the capybara, *Phoberomys* was probably a swamp dweller.

Reconstruction of *Josephaartigasia monesi*, whose bite has been estimated to match that of the modern tiger (Source: [Daily Telegraph](https://www.dailytelegraph.com.au))

(Note, added September 2018. The record was broken in 2015 by *Josephaartigasia monesi*, discovered in Uruguayan Pliocene sediments).

**Archaean sea-floor hydrothermal fluids (September 2003)**

The circulation of ocean water through new oceanic crust not only cools oceanic lithosphere sufficiently for it to droop and help drive sea-floor spreading. It also re-emerges as hot submarine springs that today host curious ecosystems, which depend entirely on energy and chemicals that spew out of these “smokers”. The chemistry of life molecules, particularly the metals in them, reveals a blend that is surprisingly similar to that of hydrothermal fluids. This, along with other matters, such as the highly primitive genetics of thermophilic bacteria, make sea-floor hydrothermal vents or the crust beneath them...
excellent candidates for the cradle of life’s origin. So getting samples of the very earliest such fluids has to be among the most exciting discoveries relevant to palaeobiology. Jacques Touret of the Free University of Amsterdam, one of the pioneers of fluid inclusion studies, believes that he has found some (Touret, J.L.R. 2003. Remnants of early Archaean hydrothermal methane and brines in pillow-breccia from the Isua Greenstone Belt, West Greenland. *Precambrian Research*, v. 126, p. 219-233; DOI: 10.1016/S0301-9268(03)00096-2).

The host rock is an undeformed, but metamorphosed breccia made of basaltic pillows from the famous Isua greenstone belt of West Greenland, which formed about 2.8 billion years ago. Quartz crystals in amygdales and veins that cement the breccia together contain minute fluid inclusions. There is little of interest in that fact alone, for most igneous or metamorphic minerals trap samples of the fluids involved in the origin of the host rocks. What is intriguing about the Isua fluids is their high content of methane and brine; just as expected from low temperature hydrothermal fluids. Their chemistry compares well with that of inclusions in altered basalts from modern oceanic crust, in which bacterial activity is implicated. Metamorphism generally results in carbon dioxide as the main carbon-containing gas in fluid inclusions. Formation of methane in sea-floor environments can be biologically controlled, but the hydration of deeper ultramafic rocks to serpentine can also generate enough hydrogen to reduce CO₂ to methane abiogenically. The full association at Isua suggests carbon-dominated hydrothermal activity, which today precipitates carbonates at vents, forming so-called “white smokers”. [“Black smokers” are sulphur dominated, and take their name from the massive precipitation of metal sulphides when the fluids emerge at the seabed.] These create alkaline conditions that are well suited to bacterial growth. Touret does not claim that the inclusions indicate living processes, merely that the right conditions were around in the earliest Archaean for life to thrive. It would be an immense feat if he subsequently discovers bacterial fossils in the inclusions, but that is highly unlikely. However, the brines might provide proxy evidence, because living cells uniquely accumulate bromine from sea water. Anomalous ratios of chlorine to bromine might point strongly towards life having been around during Isua times.


**Oxygen depletion before P-T extinction (November 2003)**

The massive die-off at the end of the Palaeozoic Era (251.5 Ma) has focussed attention from a variety of geoscientists for over a decade. Theories for the cause abound, including the climatic influence of the huge Siberian continental flood basalt province, which formed around the same time, explosive release of sea-floor methane, oceanic anoxia, continental aridity and a massive belch of sulphur from the deep mantle. There is now another candidate, asphyxiation (Weidlich, O. et al. 2003. Permian-Triassic boundary interval as a model for forcing marine ecosystem collapse by long-term atmospheric oxygen drop. *Geology*, v. 31, p. 961-964; DOI: 10.1130/G19891.1). The explosion of land plants in the Carboniferous and early Permian that led to the world’s great coal deposits drove up atmospheric oxygen levels to their all-time peak. The occurrence at that time of giant insects, whose metabolism depends on direct diffusion of oxygen, suggests levels of as high as 35%. By the end of the Permian oxygen levels may have been as low as 15%. One line of
support for such low concentrations is the growing abundance of fungal spores in the late Permian, which the authors suggest may have been related to a decline in insect populations which consume vast amounts of plant debris. Another is the widespread evidence of anoxic conditions in the Permian oceans, including isotopic features that support a “Strangelove” ocean at the P-T boundary. How oxygen was removed from the atmosphere in the Carboniferous to end-Permian is hard to assess. At levels above around 25% green vegetation catches fire easily, so large firestorms may have been characteristic of the coal-forming era. However, that would not drop levels much below those that prevail at present. Yet the Permian is famous for its continental red beds, the red coloration being due to iron oxide (hematite). Perhaps the missing oxygen became locked in Fe₂O₃ as the Earth took on a distinct reddishness as the Permian progressed.

“Archaean” ironstone pods prove to be very young (November 2003)

For a number of reasons, including evidence that the cell-chemistry of the most primitive bacteria includes heavy metals and sulphur, the most popular current theory for the place of life’s origin suggests ocean-floor hydrothermal vents. This has led to a search for remains of such “black smokers” in Archaean greenstone belts. One of the most celebrated sites is in the 3.5 Ga Barberton greenstone belt on the South Africa-Mozambique border. Within it are bodies rich in iron oxides, known as “ironstone pods” (not banded iron formations) that show many of the characteristic features of hydrothermal processes. As well as spurring many authors into concluding that the complex organic compounds in them indicate highly developed microbial ecosystems around early-Archaean seafloor vents, scientists have used fluids included in them to speculate on Archaean oceans, and the prevailing temperatures so long ago. They will be dismayed by a re-appraisal of the pods by Donald Lowe of Stanford University and Gary Byerly of Louisiana State University, which casts doubt on their antiquity (Lowe, D.R. & Byerly, G.R. 2003. Ironstone pods in the Archean Barberton greenstone belt, South Africa: Earth’s oldest hydrothermal vents reinterpreted as Quaternary hot springs. *Geology*, v. 31, p. 909-912; DOI: 10.1130/G19664.1). These pods are composed mainly of ferric hydroxide (goethite), which survives only at low temperatures, and are full of open pore spaces that include banded goethite indicating that it formed with the pores’ present orientation, The Barberton Archaean rocks are highly deformed and were metamorphosed at greenschist facies. The pods cut the foliation, and goethite is seen to partly replace Archaean cherts and serpentinised ultramafic lavas. As if these features were not sufficient to rule out the pods’ formation during Archaean times, Lowe and Byerly found one that is clearly related to a now inactive modern spring that formed terraces of botryoidal goethite. These show clear evidence of having formed as a result of modern bacterial action; they are biofilms. In places, modern landslide debris is cemented by goethite. Watch out for interesting correspondence in future issues of *Geology* from groups who stuck out their necks too far.

Artificial Archaean “fossils” (November 2003)

Debate on the existence of the world’s oldest microfossils from the 3.5 Ga Warrawoona cherts in Western Australia (see *Doubt cast on earliest bacterial fossils*, April 2002) has been stoked up by the creation of similar filamentous objects in vitro by geochemists from Spain and Australia (Garcia-Ruiz, J.M. *et al.* 2003. *Self-assembled silica-carbonate structures and...*
The detection of ancient microfossils. Science, v. 302, p. 1194-1197; DOI: 10.1126/science.1090163). They did this by mixing soluble barium salts in an alkaline sodium silicate solution (pH 8.5-11) exposed to CO₂ in the atmosphere. At high alkalinity CO₂ dissolves to enrich solutions in carbonate and bicarbonate ions. Filaments made up of precipitated barium carbonate (witherite) and silica soon form. They take on shapes very similar to the tiny segmented worm-like structures that in 1996 were trumpeted as fossils in a now notorious Martian meteorite, as well as those from Warrawoona that are disputed by Schopf and Brazier. The experimenters went a step further, by immersing the filaments in a formaldehyde-phenol mixture and heating them to 125°C. They then became coated in brownish, kerogen-like carbonaceous material, much as the Warrawoona structures are. Such organic coatings can also be produced by heating iron carbonate (siderite) to 300°C in water vapour. These “test-tube” analogues of microfossils formed in plausible chemical compositions under not particularly special physical conditions. Interestingly, the Warrawoona chert contains both baryte and iron carbonate. Reaction to the paper was mixed!

Eucarya missing from Mesoproterozoic (November 2003)

Naively, I am always surprised to learn of Precambrian oilfields, even though petroleum in the vast fields of Saudi Arabia partly had its source in Neoproterozoic sediments and migrated into the overlying cover. Provided oil has not been degraded by later biological activity, it contains chemical traces of the organisms whose original decay produced the hydrocarbons, even a breakdown product of cholesterol (cholestane) that is characteristic of the former presence of Eucarya. In the Northern Territories of Australia, Mesoproterozoic sediments (~1430 Ma) that formed in a shallow marine basin are a target for oil exploration. Potential reservoir rocks contain bitumen in pore spaces, but there are fluid inclusion in fractures, which host liquid oil and brines. Organic geochemists at CSIRO, the University of Sydney and Macquarie University have analysed the oil’s molecular structure (Dutkiewicz, A. et al. 2003. Biomarkers, brines, and oil in the Mesoproterozoic, Roper Superbasin, Australia. Geology, v. 31, p. 981-984; DOI: 10.1130/G19754.1). Gas chromatography reveals a wealth of complex organic compounds that are biomarkers for the kinds of organisms that were buried and then thermally matured to form the oil. Those from the Roper Superbasin are exclusively those that point to prokaryotes, especially the cyanobacteria. Evidence for eukaryotic organisms is completely absent. This is useful evidence in assigning a maximum age for the rise of the Eucarya that evolved into all modern complex organisms. The earliest likely eukaryote fossil is Grypania, a glossy carbonaceous spiral, found occasionally in sediments around 1400 Ma old, although dubious finds may indicate an origin as far back as 2100 Ma. The dominance of evidence for photosynthesising blue-green bacteria indicates that the oil-forming organisms thrived in an oxygenated, shallow environment. So there seems every reason to believe that Eukarya would have been capable of thriving as part of the trophic pyramid, had they arisen before 1430 Ma.

Permian-Triassic boundary and an impact? (November 2003)

More than 20 years since the proposal that the end-Cretaceous mass extinction coincided with a major impact, confirmed by the discovery of Chicxulub, nobody has produced convincing evidence for an extraterrestrial culprit for others. Were geologists implanted
with GPS tracking devices as soon as they graduated (no doubt on the cards in new health and safety regulations planned by the Blair government in Britain), then Big Brother would see strong clusters close to a number of boundaries on the geological map of the world. There would be many at P-T sites. Electronic tagging would have shown personnel from several US universities (Rochester, Harvard, California) in the Transantarctic Mountains, from time to time in the last few years. Allegedly, that near-pristine area exposes rocks at the juncture between Permian and Triassic strata over less than a metre. It is marked by the sudden disappearance of the famous Glossopteris flora, just below a clay breccia, from which this group of scientists have previously extracted evidence for shocked quartz and extraterrestrial fullerenes (football-shaped organic molecules) that contained odd noble-gas isotopes. Two members of the team have made other finds of fullerenes, at the P-T boundary in China and Japan, the K-T boundary and the ancient Sudbury impact in Canada, whereas other workers have not been so lucky. In fact, the duo are also the only people to have found fullerenes in meteorites, which is key evidence linking terrestrial finds to possible impact events. The team has hit the headlines again (Basu, A.R et al. 2003. Chondritic meteorite fragments associated with the Permian-Triassic boundary in Antarctica. Science, v. 302, p. 1388-1392). At first sight their discovery of pristine fragments of forsterite-enstatite rock with probable chondrules at the boundary suggests that indeed a major impact coincided with the biggest of all Phanerozoic mass extinctions. They even report tiny grains of metallic iron with an astonishing purity, perhaps formed by condensation from the plasma cloud associated with a really big meteorite impact. What is really odd, however, is that sedimentary rocks a quarter of billion years old should have preserved such highly unstable minerals. All other finds of fossil meteorite fragments have been highly altered relics, as any geologist would expect. There is a clamour for the Antarctic samples from other laboratories, so that the results can be confirmed or refuted. See also: Kerr, R.A. 2003. Has an impact done it again? Science, v. 302, p. 1314-1316; DOI: 10.1126/science.302.5649.1314; Oxygen depletion before P-T extinction (above)

Fossil hamster’s food cache (December 2003)

It is uncommon to find fossilised nuts, so imagine the fervour that has greeted an actual cache of them, clearly secreted by some hoarding animal. The Garzweiler lignite pit near Cologne in Germany has long been a treasure house for Miocene terrestrial fossils, thanks largely to the keen eyes of miners who work there. In 1992 they came across 1800 nuts in one of the sand horizons that divide the lignite deposit. They were in a burrow through probable dune sands. Its dimensions give a clue to the hoarder, which was about 25 cm long and weighed in at 225 grams (Gee, C.T., Sander, P.M & Petzelberger, B.E.M. 2003. A Miocene rodent nut cache in coastal dunes of the Lower Rhine Embayment, Germany. Palaeontology, v. 46, p. 1133-1149; DOI: 10.1046/j.0031-0239.2003.00337). This is about the size of an extinct hamster, remains of which have been found at a similar level in the lignites. Evidently, hamsters have always worried about their future, especially when food is likely to be scarce, but are also dim-wittedly forgetful. The hazel-like nuts are the earliest-known example of a lost food cache (about 17 Ma), and have been suggested to represent the onset of seasonality in Europe during the late Early Miocene.
The selectivity of mass extinctions (December 2003)

Every mass extinction, whatever its magnitude, was selective; there always were surviving organisms, otherwise we wouldn’t be here. However, selectivity according to the lifestyles of animals that became extinct can give important clues to the causes of extinctions. Die-off across the ecological board strongly suggests a cause that was all encompassing, such as a major impact or geochemical stress that reached into every corner, as might occur with massive flood-basalt volcanism. At the end of the Pliensbachian Epoch of the Early Jurassic there was a significant mass extinction. Its victims were mainly marine organisms, especially molluscs. Study of the disappearances of bivalve species shows that those which lived in burrows suffered more than ones inhabiting open sea floor (Aberhan, M. & Baumiller, T.K. 2003. Selective extinction among Early Jurassic bivalves: A consequence of anoxia. Geology, v. 31, p. 1077-1080; DOI: 10.1130/G19938.1). A likely cause is loss of oxygen from the upper layer of sea-floor sediments, but a less reducing environment immediately above the sediment surface.