

Palaeontology, palaeobiology and evolution

Land vertebrates snuffed at the end of the Permian (*January 2002*)

Without doubt, the mass extinction at the Permian-Triassic (P-T) boundary was the most important biological event in the history of Phanerozoic evolution. Around 80-90% of families disappeared, and perhaps more than 50% of species diversity. But, the evidence stems largely from marine records. Marine organisms went down at a hasty rate, as evidenced by the superb boundary sequence in China. However, such is the inconsistency of preservation on land that matching evidence is sparse from the terrestrial realm. The best chance of examining the response of land animals to whatever wrought such havoc at sea lies in the Karoo sediments of southern Africa. Roger Smith of the South African Museum and Peter Ward of the University of Washington have combed the mainly fluvial sediments for evidence (Smith, R.M.H. and Ward, P.D. 2001. Pattern of vertebrate extinctions across an event bed at the Permian-Triassic boundary in the Karoo Basin of South Africa. *Geology*, v. **29**, p. 1147-1150; DOI: 10.1130/0091-7613(2001)029<1147:POVEAA>2.0.CO;2). Rather than supporting the general view that terrestrial P-T extinctions took a few million years, they have been able to show that Permian vertebrates disappeared abruptly, to be replaced by a very different fauna equally suddenly in the lowermost Triassic. Only one genus (*Lystrosaurus*) spans the boundary, and the boundary itself contains no evidence of life. Calculations based on estimates of the rate of sedimentation point to around 50 thousand years for the extinction event, about the same as that affecting marine organisms. Interestingly, the event sharply separates very different sediments, that Smith and Ward interpret as products of perennially wet Permian flood plains and those experiencing ephemeral flow in the Triassic (see [End-Permian devastation of land plants](#) October 2000). Whatever its cause, the stresses placed on land vertebrates seem to have included the sudden onset of aridity.

Mesozoic fossil hunting in Madagascar (*January 2002*)

Most papers on palaeontology report the details of years of research on what the fossil hunters have found, with mentioning the months of patient searching. John Flynn and André Wyss have provided an insight into the tribulations of palaeontological field work in difficult terrains, as well as a broad account of the context of their finds (Flynn, J.S. and Wyss, A.R. 2002. Madagascar's Mesozoic secrets. *Scientific American*, v. **286**, February 2002, p. 42-51). Madagascar lingered at the heart of the Gondwana supercontinent until it finally began to split into drifting segments during the early-Triassic. It lay on the eastern flank of an evolving rift basin that filled with mainly terrestrial sediments until the late-Jurassic. This particular basin remained uninterrupted by volcanism or erosion, and so is a repository for organic remains trapped in a continuous sedimentary sequence. This period in geological history, particularly the Triassic, spans the emergence and development of both the dinosaurs and primitive mammals. The wealth of vertebrate fossils that geologists are beginning to unearth suggests that Madagascar may well become the site where the mysterious origins of both are resolved.

The simplest living ecosystem (January 2002)

Hugely complex as life is, at the cell level it has a profound simplicity, at least as regards its fundamental chemistry. Cell metabolism receives its power from the transfer of electrons from a high to a low energy level. High-energy electrons stem from chemically active molecules, atoms or ions able to release them; electron donors or reducing agents. The metabolic path ends in oxidizing agents accepting these electrons. This process of donating and accepting electrons takes the form, in most cell types, of “pumping” hydrogen ions, or protons back and forth across the cell wall to create an electrochemical gradient that is continually charged and discharged. Biochemistry reflects this by the ADP-ATP cycle at life’s core, in many different versions.

The simplest provision of electrons is by hydrogen, and arguably a supply of hydrogen gas is a highly likely precondition for the origin of life. Surprisingly, hydrogen is generated by many geological reactions, although little survives some form of oxidation for long. In a few places hydrogen gas escapes abundantly, as in the weathering of ultramafic rocks by groundwater. The essential process is the breakdown of iron and magnesium silicates to various kinds of clay, by the interaction of hot water with fresh igneous rocks. Geochemists and microbiologists from the USA analysed such a hydrothermal system 200 m beneath a volcanic area in Idaho, and found a thriving and diverse ecosystem dominated by simple organisms that do depend on hydrogen (Chapelle, F.H. *et al.* 2002. [A hydrogen-based subsurface microbial community dominated by methanogens](#). *Nature*, v. **415**, p. 312-315; doi: [10.1038/415312a](#)). More than 90% of the organisms are methane-producing Archaea, which reduce carbon dioxide to methane, using hydrogen. No other hot-spring system comes close to this probably highly primitive community. It is a handy analogue for the kind of ecology that may have developed if life has arisen deep beneath the icy surface of Europa - a target for future NASA missions.

Incidentally, the exploitation of electron and proton transfer that underpins cell metabolism potentially forms a source of electrical power. Younger readers may have experimented with using fruit as the basis of a simple galvanic battery, thereby exploiting low pH conditions. Investigation of the potential of bacteria for direct electricity generation recently made a breakthrough (Bond, D.R. *et al.* 2002. [Electrode-reducing microorganisms that harvest energy from marine sediments](#). *Science*, v. **295**, p. 483-485; DOI: [10.1126/science.1066771](#)). A member of the family Geobacteraceae (*Desulfuramonas acetoxidans*) has been found to readily produce excess electrons as it metabolises organic material in oxygen-free muds. Daniel Bond and co-workers from the University of Massachusetts and the US Naval Research Laboratory introduced graphite electrodes into airless fish-tank muds and the upper oxygenated sediments. Even with such a crude experiment, sufficient current flowed to power a small calculator. Moreover, *D. acetoxidans* colonised the electrodes within a matter of days, showing that they were directly involved in the oxidation-reduction system at the root of such a fuel cell. As well as raising the possibility of powering submarine monitoring devices using bioelectricity, such geobacteria are able to metabolise a range of common organic pollutants. Marine organic sediments are virtually limitless, so it is not inconceivable that the process may result in yet another renewable power source, albeit difficult to convert to high-power supplies, with the blessing of pollution control as a sideline,

Extinctions by impacts: smoking artillery (*February 2002*)

It's a measure of the resistance to events controlled by processes outside of Earthly ones that evidence in support of an impact cause for mass extinctions has assumed monumental dimensions. The iridium anomalies at the K-T boundary, found by Alvarez and Son in 1980, were never enough for a great many palaeontologists. Nor, for that matter, were the co-occurrences of glass microspherules, shocked quartz grains and soot, discovered by later investigators at 30 to 100 sites worldwide. Even the remains of the 180 km-wide Chixculub impact crater that formed at the same time as the extinction event, off Yucatan in the Mexican Gulf, was insufficient for the most intransigent sceptics. That the sooty material contained massive carbon molecules in forms akin to Buckminster Fuller's geodesic dome, and moreover those fullerenes contained trapped noble gases in proportions that could never have been present on Earth, formed the smoking siege gun for most sensible scientists. The fullerenes contain helium, neon and argon with isotopic proportions comparable with those in carbonaceous chondrites and interplanetary dust, probably created by processes in a supernova that preceded accretion of the solar nebula. The hypothesis that such odd materials were delivered to the K-T boundary layer by an extraterrestrial object was amply confirmed by Luann Becker's discovery that carbonaceous chondrites, never affected by extreme events since they formed, also contain fullerenes (Becker, L. 2002. Repeated blows. *Scientific American*, v. **286**(3), p. 62-69). The latest occurrence of such convincing evidence for impact control of mass extinction comes from Permian-Triassic boundary deposits in China, Japan and Antarctica, that coincide with the most severe disruption of eukaryote life - around 90% of marine and continental families failed to survive it (see *Land vertebrates snuffed at the end of the Permian* above).

It now seems that palaeontologists and a great many others, including creationists who envisage some kind of design within the fossil record, will be compelled to face up to an unearthly influence over the shaping of life on our planet. There are many impact structures that are candidates for having affecting the biosphere from the Mesoproterozoic onwards, yet no pattern to their timing and energy of formation. Such is the complexity of gravitational fluctuations that fling asteroids and comets into Earth-crossing orbits, that aside from the inevitability that, given time, they will strike with devastating consequences, they are essentially random events. Our species is a late development from a vast concatenation of events, both from outside and within the Earth system, that spanned the entire 4.5 billion-year physical evolution of our home world. No-one has yet turned statistics to estimate the likelihood of such chance occurrences being repeated, with one outcome being conscious beings. If that were possible, then for the seekers of extraterrestrial intelligence, it might well be as welcome as a Semtex suppository on a wide-bodied jet!

Dinosaur digest (*February 2002*)

Having suffered vivid nightmares about dinosaurs when a kid - I did not even dare watch Jurassic Park alone as an adult - it comes as a huge relief to learn that the scariest of all monsters, *T. rex*, was about as agile as I am. Indeed, it seems highly likely that you or I could outrun one. The reasoning behind this welcome news (Hutchinson, J.R and Garcia, M. 2002. [Tyrannosaurus was not a fast runner](#). *Nature*, v. **415**, p. 1018-1021; doi: 10.1038/4151018a) stems from scaling up the sprinting powers of chickens (a chicken is surprisingly fast!) to the

estimated 6 tonne weight of an adult *T. rex*. The analysis involves two factors. First, muscle proteins have the same capacity for powering movement, and the total power of musculature depends on its cross-sectional area, but while body mass and volume grows, this area and potential power falls behind. Secondly, the bearing capacity of bone decreases with size too, because this also depends on area rather than volume. Hutchinson and Garcia's scaling hens to 6 tonnes, and calculating the necessary mass of leg muscle to propel them in their fearsome dashes to grab a tidbit (you or me), resulted in the absurd vision of a creature with 86% of its body mass in its legs. Tyrannosaur modelling from their skeletons falls a very long way short of that, and they would be hard pressed to clock much more than 5 ms^{-1} , which I think I could manage quite easily, for a short while. That they would ever break into more than a fast walk is unlikely, for the second factor poses a limit. One wrong pounce would be curtains, for they would break a leg. Two possible life styles seem to emerge from the analysis. They may have subsisted on carrion. Alternatively, the far bigger herbivorous dinosaurs would have been even more stately, for the same mechanical reasons, which generates the absurd vision of large carnivorous dinosaurs ambling down their prey.



You could have outrun this beast: unless you were rooted to the spot with fear!

See also: Hecht, J. 2002. *T. rex* was a lumbering old slow coach. *New Scientist*, 2 March 2002, p. 6; Biewener, A.A. 2002. [Walking with tyrannosaurs](#). *Nature*, v. **415**, p. 971-973; doi: 10.1038/415971a.

That dinosaurs could survive high-latitude winters, in near total darkness, if not glacial conditions, was first suspected in 1960 when their footprints turned up in Spitzbergen. Since then, palaeontologists have found fossils of a wide variety of dinosaurs in areas that would have been near-polar during the Jurassic and Cretaceous Periods (Rich, T.H. *et al.* 2002. [Polar dinosaurs](#). *Science*, v. **295**, p. 979-980; DOI: 10.1126/science.1068920). Surely,

these dinosaurs must have been warm-blooded, as their containing sediments sometimes show signs of the effects of permafrost. There are signs in some of the fossils for heightened visual powers too. In the case of Australian faunas, it seems certain that the abundant dinosaurs there did not migrate to high latitudes in summer, because seaways blocked passage to lower latitudes.

Extremophiles and possibilities for extraterrestrial life (*February 2002*)

Bacteria can survive extremes of temperature (-10 to 110°C) and chemistry, and the biosphere extends to crustal depths in excess of 2 km, as shown by thriving communities in deep wells. So far as biologists are aware, temperature forms the limit to life's range, because of the instability of crucial molecules and of course the boiling point of water. Since temperature increases with depth in the Earth, due to its self-heating by radioactive decay, the biosphere has a depth limit too, depending on the geothermal gradient. However, recent experiments on two common bacteria show that life can survive at extremely high pressures (Sharma, A. *et al.* 2002. [Microbial activity at gigapascal pressures](#). *Science*, v. **295**, p. 1514-1516; DOI: 10.1126/science.1068018). By compressing bacterial films on ice in diamond anvil cells, a team from the Carnegie Institute in Washington, DC have shown that simple life can survive pressure as high as 1.6 Gpa, that is equivalent to crustal depths of 50 km or an ocean bed 160 km below the surface. Because subduction takes cold lithosphere downwards, and the associated geothermal gradient is low in such environments, the deepest biosphere may be below volcanic arcs. However, the most significant implication of the experiments is that probing the icy crusts of Europa, Ganymede or Callisto (and liquid water that might be present at great depths there) and the Martian ice caps, conceivably could reveal living organisms, if life ever evolved on these bodies. Whereas this possibility encourages various plans for such exploration, what the experiments did not show was replication by the bacteria, and that is central to any living organism.

Earlier date for first suspected animals (*March 2002*)

The earliest indisputable traces of metazoan animals are quite literally that - the impressions of soft-bodied organisms preserved as the Ediacaran fauna of Australian and other late-Neoproterozoic sediments dated around 565 Ma. However, the profound differences in genetic make-up of existing animal phyla, which clearly at the time of the Cambrian Explosion, have been expressed as indicators of animals' origins more than a billion years ago. Consequently, the discovery in 1998 of what appeared to be non-Ediacaran trace fossils in the Neoproterozoic Vindhyan Supergroup of India triggered considerable interest. The problem with many of India's Precambrian sediments is their lack of precise and verifiable dates. Occurrences of the sedimentary silicate glauconite in the Vindhyan prompted use of the K-Ar method, which suggested that they were pre-1100 Ma, but that is a notoriously unreliable technique. Part of the lower Vindhyan succession contains poorly crystalline clays that show textural evidence for having originated at ignimbrites, and they contain zircons of volcanic origin. Once sampled, it was only a matter of time before precise single-zircon U-Pb dates became available. In fact, two teams published simultaneously in the February issue of *Geology*, and gave similar ages from different places (Ray, J.S. *et al.* 2002. [U-Pb zircon dating and Sr isotope systematics of the Vindhyan](#)

[Supregroup, India](#). *Geology*, v. **30**, p. 131-134; DOI: 10.1130/0091-7613(2002)030<0131:UPZDAS>2.0.CO;2. Rasmussen, B. *et al*, 2002. 1.6 Ga U-Pb zircon ages for the Chorhat Sandstone, lower Vindhayan, India: Possible implications for early evolution of animals. *Geology*, v. **30**, p. 103-106; 10.1130/00917613(2002)030<0103:GUPZAF>2.0.CO;2). The first paper gave an age of 1631 Ma for strata immediately beneath the supposedly fossiliferous formation, whereas the second bracketed it between 1628 and 1600 Ma for rocks beneath and above it.

If the structures preserved in the Chorhat Sandstone do prove to be true trace fossils, there will be little doubt that animals appeared at least three times earlier than the previous fossil-based estimate, more in line with the molecular evidence. However, the structures are disputed, and there is another oddity about the palaeontology of the Vindhyan. Limestones that conformably overly the 1600 Ma dated horizon have been reported to contain brachiopods and “small, shelly faunas” typical of the earliest Cambrian elsewhere. Since the limestones are only a few hundred metres higher in the Vindhyan sequence, and contain $^{87}\text{Sr}/^{86}\text{Sr}$ isotope ratios that are appropriate for Neoproterozoic seawater, brings their content of Cambrian fossils into doubt. Clearly, a great deal more work is needed to resolve the significance of the Vindhyan finds, particularly establishing accurate, basin-wide stratigraphic correlation.

Are mass extinctions artefacts of sampling bias? (March 2002)

Evidence for mass extinctions comes from inventories of fossil species, genera and families collected from the sedimentary record. There has always been a geographic bias in this sampling towards more accessible areas and those with the greatest number of palaeontologists, i.e. towards rich countries. Increasing grants for expeditions to remote areas and the slow growth in numbers of specialists in less well-endowed countries does smooth out the bias. However, because of many factors, including ups and downs in sea level and the effects of orogeny on rates at which deformed sediments have been eroded, the stratigraphic record itself does not accurately represent time with exposed rocks.

The data on which extinction records rest are those compiled by the late Jack Sepkoski, yet until recently there has been little attempt to weight them according to stratigraphic record, although much statistical re-evaluation has gone on (e.g. *The “Big Five” become the “Big Three”?* above). This stratigraphic evaluation to some extent pulls the rug from under those who speculate on the causality of extinction (Peters, S.E. and Foote, M. 2002. [Determinants of extinction in the fossil record](#). *Nature*, v. **416**, p. 420-424; doi: 10.1038/416420a). A great many ups and downs in the fossil record do seem to depend on the amount of exposed sedimentary rock. Widespread gaps in the sedimentary record result in spurious and abrupt ends to evolutionary lineages; pseudo-extinctions. Although the period- and era-ending extinctions seems still to be statistically valid, those at stage boundaries are suspect. One of the lessons to be learned is that the previous good correlation between sea-level change and extinction and origination rates is particularly suspect, as eustasy is a first-order contributor to changes in sedimentary deposition and preservation.

Doubt cast on earliest bacterial fossils (March 2002)

In autumn 1996 two of the most blatant hyperboles in the recent history of the Earth sciences hit the world's headlines; two groups of scientists, one from the USA, the other British, announced their discovery of fossil life forms in meteorites reputed to have originated on Mars. The evidence was in the form of organised structures revealed by scanning electron microscopy. Subsequently, most biologists and palaeontologists concluded that the case was, in the manner of the third possible verdict in Scottish courts, "not proven". Kindly scientists regarded the hype as being prematurely optimistic. However, critical attention focussed on the announcements because they claimed first discovery of extraterrestrial life. If one finds a mammoth while digging a ditch, there is some cause for celebration, and the world will believe and congratulate the finder, for the mammoth is unmistakable. That is not the case for fossilized micro-organisms. In 1993, William Schopf of UCLA, and co-workers, announced their discovery of the oldest known fossil bacteria in 3465 Ma cherts in a greenstone belt near Marble Bar in Western Australia. They were microscopic wisps of carbonaceous material, that a trained eye might resolve into filaments made of bacterial cells. Since the most common living filamentous bacteria are photosynthetic cyanobacteria, that bear close resemblance to sketches of the ancient structures, Schopf and colleagues performed the palaeontological equivalent of Aristotle's syllogism, by declaring that indeed some of the structures were blue-green bacteria. In what was generally regarded as an anoxic Archaean world, it seemed there were organisms working to oxygenate the environment. Various lines of evidence, such as the isotopic composition of carbon in Archaean sediments, were later claimed by others to support such an early arrival of cyanobacteria, that eventually transformed the atmosphere and the conditions for life, so that oxygen-demanding Eucarya, such as ourselves, might evolve and diversify.

There is one snag with the Marble Bar chert. It almost certainly formed by hydrothermal activity on the Archaean ocean floor; deep and dark. Photosynthesis using solar energy would be unlikely. Re-examination of the putative fossil filaments, using both microscope and Raman spectroscopy (means of estimating C/H ratios from spectra excited from carbonaceous matter by a laser) has raised a minor storm. Martin Brazier of Oxford University and colleagues from Britain and Australia question the biological origin of the structures (Brazier, M.D. *et al.* 2002. [Questioning the evidence for Earth's oldest fossils](#). *Nature*, v. **416**, p. 76-81; DOI: 10.1038/416076a). Amazingly, one of their observation while examining Schopf's original material with a high powered microscope was that by racking the objective up and down to visualize the structures in 3-D, most showed to be highly irregular smears of carbonaceous stuff. Only one position provided life-like shapes. While Brazier *et al.* do not deny that life was around in the chert-forming hot spring - probably chemautotrophic prokaryotes - they are convinced that Schopf's structures are artefacts formed by hydrothermal reworking of degraded organic molecules. In a rejoinder, Schopf and US colleagues accept the deep-water, hydrothermal origin of the cherts and concede that none of the structures are blue-green bacterial cells, but still maintain that they are biogenic (Schopf, J.W. *et al.* 2002. [Laser-Raman imagery of Earth's earliest fossils](#). *Nature*, v. **416**, p. 73-76; DOI: 10.1038/416073a). The earliest undisputed fossil micro-organisms are almost 1.4 billion years younger than those of Marble Bar. They are from cherty layers in banded iron formations, formed probably in shallow water by the combination of oxygen

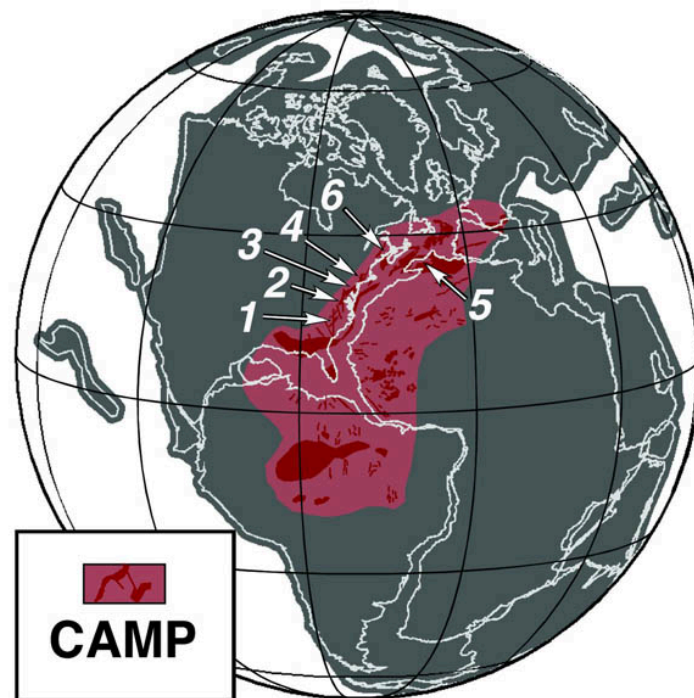
produced by cyanobacteria with dissolved ferrous iron. The Archaean contains plenty of BIFs, and perhaps a search for the oldest biotas in them would give more definite results.

See also: Kerr, R.A. 2002. [Earliest signs of life just oddly shaped crud?](#) *Science*, v. **295**. P. 1812-1813; DOI: 10.1126/science.295.5561.1812.

And now, the Tr-J boundary (April 2002)

Despite the downgrading of the raw data for mass extinctions by their stratigraphic weighting (see *The “Big Five” become the “Big Three”?* above), which cast doubt on the magnitude of the Triassic-Jurassic boundary event, the Tr-J draws attention because something out of the ordinary did happen then. In terms of changes in fauna and flora, the boundary is globally recognisable. The giant Manicouagan crater in Quebec formed almost at the boundary, and the Central Atlantic Magmatic Province (CAMP) had about the right timing too - 202 to 198 Ma ago. The CAMP was the magmatic expression of the first substantial break up of Pangaea. Carbon isotopes in sediments reflect changes in the inorganic and organic parts of the C-cycle, and it seems that a significant excursion from the norm characterizes the change from Triassic to Jurassic biota at four important sections in western Canada, Hungary, Britain and East Greenland (Hesselbo, S.P. *et al.*, 2002).

[Terrestrial and marine extinction at the Triassic-Jurassic boundary synchronized with major carbon-cycle perturbation: A link to initiation of massive volcanism?](#) *Geology*, v. **30**, p. 251-254; DOI: 10.1130/0091-7613(2002)030<0251:TAMEAT>2.0.CO;2).



Continental reconstruction at the end of the Triassic with the probable extent of the Central Atlantic Magmatic Province superimposed; dark red patches indicate exposed end-Triassic igneous rocks. (Credit: Blackburn *et al.* 2013 Fig. 1; DOI: 10.1126/science.1234204)

Around the palaeontologically defined boundary, each section records a sharp decrease in the proportion of heavy ^{13}C to light ^{12}C ($\delta^{13}\text{C}$), followed by a protracted period dominated by isotopically light carbon in the earliest Jurassic. Such a shift must indicate some kind of

global change in the C-cycle. One explanation is an increase in the amount of CO₂ expelled from the mantle by major volcanic activity, which tallies with the CAMP. If that was the reason, then $\delta^{13}\text{C}$ would be a proxy for all manner of other effects of volcanic activity - acid rain, atmospheric dust as well as volcanic enhancement of the "greenhouse effect". However, as several long-running sagas have shown, isotopically light carbon recorded in sediments can also be explained by methane escape from deep sediments, and even by a massive reduction in biological activity that would otherwise sequester light carbon through metabolism. More confusion arises from the carbon that is isotopically analysed. That in carbonate sediments records the isotopic composition of carbon dissolved in seawater, while that found as carbon in preserved organic matter tells a different story. The Tr-J data are from bulk organic carbon in reduced sediments, and relates to the reservoir of carbon on which cell metabolism has drawn - CO₂ dissolved in seawater, and that in the air for marine and terrestrial life respectively, both of which are in equilibrium. It looks like the excursion stemmed from an increase in volcanic emissions to the atmosphere, and the CAMP. However, the study by Stephen Hesselbo and colleagues from the Universities of Oxford and Copenhagen, and the Geological Survey of Denmark and Greenland, reveals a glitch. The appearance of the ammonite genus *Psiloceras* has generally been taken to mark the start of the Jurassic. In Canada, such fossils occur just after the first major shift in carbon isotopes, whereas in Britain *Psiloceras* appears considerably later. One takes one's choice: either ammonite species appeared synchronously everywhere (assuming that they were pelagic ocean-crossers like modern *Nautilus*), or signs of change in the C-cycle are truly global. Because of very rapid mixing of air and water, on geological timescales, the latter is like to be true and faunal zones are not so reliable as stratigraphers believed over the last century. It seems that as well as tying whatever happened at the Tr-J boundary to massive volcanism, the study marks a turn from traditional palaeontology to geochemical markers as the "golden spikes" in stratigraphy.

There are other means of linking changes in the pace of volcanism and the surface environment, that emerge by careful choice of geochemical proxy data. A long used, but imprecise approach depends on the much slower rate at which radiogenic ⁸⁷Sr builds up in the mantle than in the continental crust, because of the much lower rubidium content of the mantle. Oceanic strontium isotopes, measured for the past by analysing marine carbonates, reflect the derivation of strontium by erosion and weathering of continental crust, and addition of strontium to sea water by its hydrothermal interaction with newly emerged volcanic rocks at constructive margins or on oceanic plateaux (submarine flood basalts). Since the ⁸⁷Sr/⁸⁶Sr ratio of seawater is a commonly used proxy for varying rates of continental weathering, identifying signs of massive increases in submarine volcanism is only possible when carbonates reveal extremely low values of the ratio. The mantle is enormously richer than continental crust in elements likely to have entered the core preferentially, such as gold and especially the platinum group elements. Partial melting allows unusually high amounts of such elements to enter basalt magmas, and the lavas and ejecta that enter the surface environment. Potentially, the environmental abundance of such normally exceedingly rare elements is a reliable proxy for major magmatic events. Osmium isotopes are particularly promising, even in tiny concentrations, because two (¹⁸⁷Os and ¹⁸⁸Os) are daughters of the decay of unstable rhenium isotopes. The details of their use is complex. As well as the exceedingly light carbon isotopes in sediments at and around the Tr-J boundary, marine shales also reveal a sudden increase in osmium abundance, the ¹⁸⁷Os/¹⁸⁸Os ratio and the abundance of rhenium (Cohen, A.S. and Coe, A.L. 2002. New

geochemical evidence for the onset of volcanism in the Central Atlantic Province and environmental change at the Triassic-Jurassic boundary. *Geology*, v. **30**, p. 267-270; 10.1130/0091-7613(2002)030%3C0267:NGEFTO%3E2.0.CO;2). The most likely source for globally distributed anomalies of this kind are the volcanic rocks associated with the CAMP, and their reaction with both rainfall and hydrothermal fluids. However, the data do not rule out an extraterrestrial influence by a major impact. That the Tr-J boundary is associated with both the CAMP and the Manicougan impact seems likely to vex geochemists hoping to tie things down to any single trigger.

Rise of the dinosaurs after the Tr-J event (*May 2002*)

Whatever happened at the Triassic-Jurassic boundary (around 200 Ma ago), the palaeontological shifts then coincided with eruptions of flood basalts of the Central Atlantic Province and the start of Atlantic opening (see *And now, the Tr-J boundary* above). Although questioned as a mass extinction event, the boundary contains extremely high proportions of fern spores, that may signify the land being cloaked by rapidly spreading ferns after it had been wiped clean of other vegetation. New evidence suggesting the influence of an impact at the time emerges from a geochemical study of the fern-rich boundary layer (Olsen, P.E. and 9 others 2002. [Ascent of dinosaurs linked to an iridium anomaly at the Triassic-Jurassic boundary](#). *Science*, v. **296**, p. 1305-1307; DOI: 10.1126/science.1065522), which revealed anomalously high levels of iridium. High iridium is only one pointer to possible extraterrestrial influences, and the clinching factor of shocked mineral grains has yet to be shown convincingly.

The novel feature of the paper by Paul Olsen of the Lamont-Doherty Earth Observatory and colleagues from the USA, Canada, Italy and Austria is how they used trace fossils to reach a remarkable conclusion. They combed eastern US terrestrial sediments either side of the boundary for reptilian foot prints. They tracked time using evidence for climate change paced by Milankovich cycles. Their records of 10 thousand sets of tracks show a decline in non-dinosaur footprints, and a jump in the proportion left by dinosaurs from 20 to 50% of the total, as the boundary is crossed. Those of some Triassic reptiles that had survived for 20 Ma end abruptly at the boundary. It seems that, whatever the boundary event was, early dinosaurs were able to adapt to change better than evolutionarily more primitive reptiles, so that they could speciate rapidly when their Triassic companions bit the dust. Dinosaur evolution seems to have been similar to that of the mammalian adaptive radiation that followed the K-T extinction event.

Gigantic claims for “geogenomics” (*May 2002*)

Fossils and their stratigraphic ages no longer offer the only clues to biological evolution, now that it is possible to judge the degree of relatedness between living organisms from sequences of genes and proteins that their cells contain. The molecularly inferred family trees of modern animals, plants and micro-organisms help scientists to visualize the relative antiquities of the sharing of a common ancestor by different pairs of a living group. By assuming constant rates for genetic mutation and protein evolution, some palaeobiologists have asserted that they are able to assign absolute ages to evolutionary divergences. If that were so, then it would be possible to correlate evolutionary milestones with

transformations brought on by geological and climatic upheavals, and also with other past changes in the biosphere. Good examples would be linking fossil and genetic changes in ruminant mammals to the rise of grasses, or the rise and divergence of corals following the end-Permian mass extinction. The inter-linkage between palaeontology and genomics is in its infancy. That it promises a great deal by way of insights, as well as possible bloomers, is nicely brought out by a recent review (Benner, S.A. *et al.* 2002. [Planetary biology - paleontological, geological and molecular histories of life](#). *Science*, v. **296**, p. 864-868; DOI: 10.1126/science.1069863). Whether charting the “planetary proteome” will become “a civilization-wide enterprise”, as Steven Benner and his colleagues predict, is something that I would not care to comment on during the 2002 World Cup. As Bill Shankly once observed, when asked if football was a matter of life and death, his reply was “It’s more important than that”...

Too much iron, too little phosphorus delayed an oxygen-rich atmosphere (May 2002)

The age of the earliest blue-green bacteria hinges on the imagination of some palaeobiologists and how well they can focus a microscope (*Doubt cast on earliest bacterial fossils*, above). Without doubt, it was blue-greens that first began breaking the chemical equilibrium of water to release free oxygen to the environment, yet it was some 2.5 billion years after the Earth had formed that atmospheric oxygen had a tangible effect on the Earth's bare surface. In rocks around 2.2 to 2.0 Ga old geologists find the first evidence for that in soils that are rich in oxidized Fe-3. For iron to lose an electron and change from soluble Fe-2 to Fe-3, whose oxides and hydroxides are highly insoluble, demands the abundant presence of an electron acceptor, or oxidizing agent. The most likely of these in the atmosphere and hydrosphere is oxygen. However, there are sedimentary rocks that form vast repositories of Fe-3 and oxygen that predate the first well-accepted oxygen-rich atmosphere. They are known as banded iron formations or BIFs, whose minuscule layering seems to signify that they formed as precipitates from water, when dissolved Fe-2 met a source of oxygen to produce hematite - Fe_2O_3 - and goethite - $\text{Fe}(\text{OH})_3$. BIFs signify deep ocean water devoid of oxygen, to enable soluble Fe-2 to circulate abundantly, yet a sizeable supply of oxygen where they were precipitated. Since only organic photosynthesis is capable of breaking the powerful bond in water, some kind of photosynthetic bacteria are implicated in the formation of BIFs. Whether or not palaeobiologists and geochemists can demonstrate evidence for the first appearance of such bacteria, BIFs more or less prove their existence, in the absence of any other plausible means of formation.

Until recently, the huge delay in the Earth's surface environments becoming oxygenated has been ascribed to the mopping up of any biogenic oxygen by its reaction with a vast excess of dissolved Fe-2. However, once blue-green bacteria evolved photosynthesis, their chemical trick of splitting water molecules to provide hydrogen for processes at the cell level should have meant that they would have spread like wildfire across the ocean surface. In that respect they are unique among bacteria, most of which exploit very narrow ecological niches. Oxygen should have quickly come to dominate both oceans and atmosphere. That is, unless there was some check on the living ocean biomass. It turns out that BIFs may contain the answer, for they are rich in phosphates, adsorbed onto the surfaces of their iron minerals (Bjerrum, C.J. and Canfield, D.E. 2002. Ocean productivity before about 1.9 Gyr ago limited by phosphorus adsorption onto iron oxides. *Nature*, v. **417**, p. 159-162; doi: 10.1038/35019044). Phosphorus is vital in any organism, being an essential component of

nucleic acids and phospholipids. By working out the partition coefficient between water and iron oxide, and estimating the production rate of BIFs before 1.8 Ga when their production ceased, Bjerrum and Canfield conclude that phosphorus was an order of magnitude less abundant in sea water until then. Such a deficiency in a vital nutrient would have limited the scope of blue-greens, and the rate at which they produced oxygen.

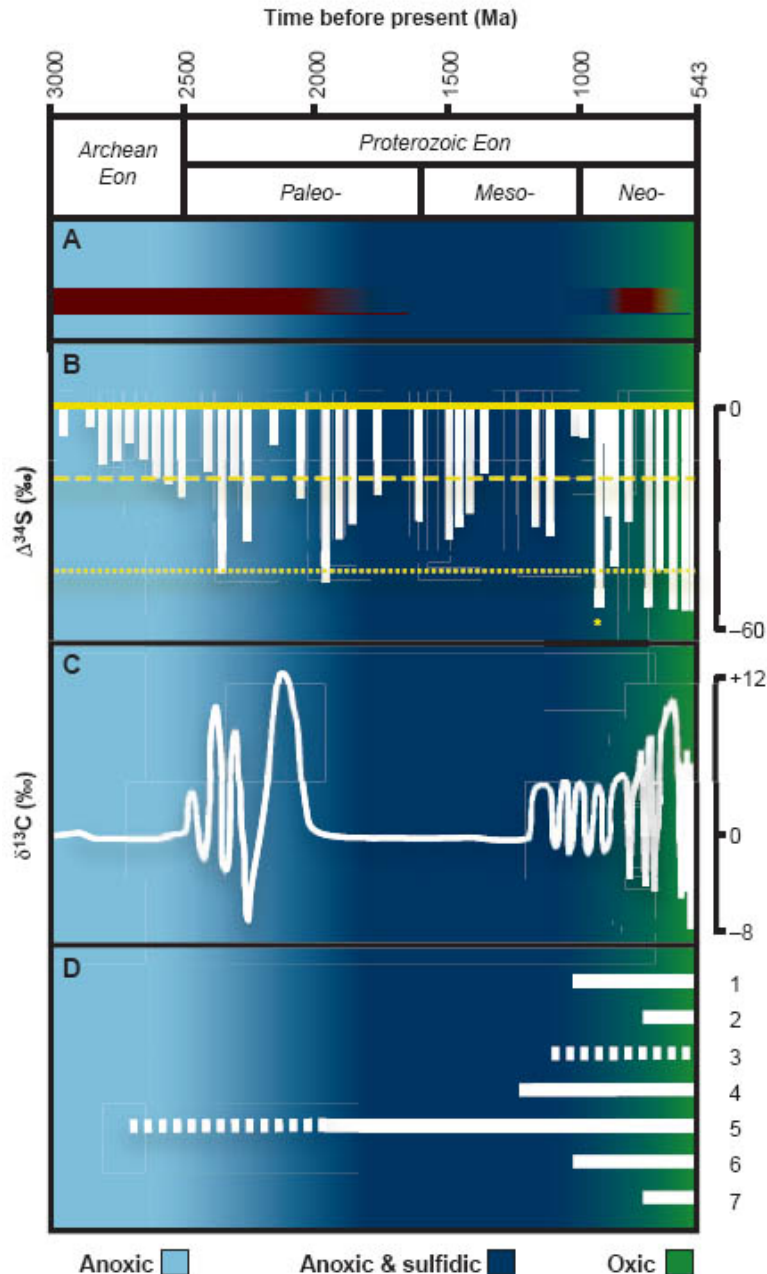
Just why the Fe-P checks and balances on oxygen production collapsed around 2.2 to 1.8 Ga is something of a mystery. One possibility is that the iron concentration in sea water fell, perhaps as sea-floor spreading waned from its high early rates; basalt magma provides the main input of iron through ocean-floor hydrothermal activity. Less production of BIFs would leave more phosphorus in solution, helping greater biological productivity, whose oxygen output would eventually remove soluble iron from sea water.

See also Hayes, J.M. 2002. A lowdown on oxygen. *Nature*, v. **417**, p. 127-128; DOI: 10.1038/417127a .

The Malnourished Earth - evolutionary stasis in the mid-Proterozoic (August 2002)

Accepted biogeochemical wisdom suggests that about 2000 Ma ago, the terrestrial environment changed from one in which oxygen was a rare free element to an increasingly oxygenated world. One line of support for this involves the first appearances around that time of redbeds and lateritic palaeosols, that signify a surge in the O₂ content of the atmosphere. The other pointer is the disappearance of banded iron formations (BIFs), suggesting that soluble iron-2 was no longer available in the oceans due to its oxidation near its main source at mid-ocean ridges. The first unambiguous microfossils of eukaryotes, which need oxygen for their metabolism, also appeared some two billion years ago.

There is, however, a different view; that there was a transition between the anoxic world of the Archaean and Early Palaeoproterozoic and that marked by pervasion of atmosphere and hydrosphere by oxygen. It stems from studies of sulphur isotopes in Proterozoic marine sediments by Donald Canfield of Odense University Denmark (Canfield, D.E., 1998. A new model for Proterozoic ocean chemistry. *Nature*, v. **396**, p. 450-453; DOI: 10.1038/24839). Canfield found evidence for steadily increasing sulphate ions in seawater from 2300 Ma, which he suggested would have led to increasing production of hydrogen sulphide in the deep oceans by sulphate-reducing bacteria. He proposed that it was combination with deep-ocean sulphide ions that shut off the supply of soluble iron-2, essential for the production of shallow-water BIFs. Today, sulphide precipitation is restricted to hydrothermal vents and most iron is removed by combination with oxygen in sediments on the main ocean floors. In short, Canfield proposed a transitional ocean akin to the Black Sea, with an oxic near-surface zone but anoxic at depth. Not only iron would have been removed in sedimentary sulphides but many other siderophile (sulfur-loving) metals too, including molybdenum, leading to their depletion in seawater. Ariel Anbar of the University of Rochester and Andrew Knoll of Harvard examine the biological repercussions of this transitional ocean (Anbar, A.D. & Knoll, A.H. 2002. [Proterozoic ocean chemistry and evolution: a bioinorganic bridge?](#) *Science*, v. **297**, p. 1137-1142; DOI: 10.1126/science.1069651).



Biological and geochemical changes during the Proterozoic Eon. The left to right colour changes signify possible changes in deep sea redox conditions. A shows periods of BIF deposition; B changes in sulfur isotopes; C changes in C isotopes; D first appearances of various eukaryotes. (Credit: Anbar & Knoll. 2002; Fig. 1

Iron and molybdenum are crucial elements for eukaryotes, albeit only in small quantities, because they are central to the enzymes that fix nitrogen. Insufficient quantities would put early eukaryotes at an evolutionary disadvantage to prokaryote life. Moreover it would reduce ocean productivity. This, the authors propose, can help explain the lack of evolution among eukaryotes until the late Proterozoic. The carbon isotope record of seawater (B – derived from limestones) shows a strange pattern that supports a period of biological stasis from 2000 to about 1200 Ma. From the end of the Archaeon until 2 billion years ago, there are huge fluctuations (to highly positive and negative values) in the proportion of heavy ^{13}C , and so too in the Neoproterozoic. The period in between shows no significant carbon-

isotope fluctuation, $\delta^{13}\text{C}$ remaining at around zero, which Anbar and Knoll attribute to very low biological productivity. In their model, it was the release of massive amounts of metals by continental erosion during the “Snowball Earth” glacial periods of the Neoproterozoic that was able to kick start life, especially that of the eukaryotes. Emergence of the efficient, multicelled algal photosynthesizers drove up oxygen levels, eventually to oxygenate the deep oceans.

A cautionary note needs to be thrown in, however, especially when using analogies with the modern Black Sea (see *Analogue of Archaean carbon cycle in Black Sea reefs* Palaeoclimatology 2002). Biogenic carbonates on the Black Sea bed show huge negative excursions in their $\delta^{13}\text{C}$, because organisms that formed them metabolized methane, thereby incorporating methane’s strong depletion in heavy carbon. As well as there being little direct evidence for Anbar and Knoll’s idea, the methane part of the carbon cycle needs to be factored into interpretations of the carbon-isotope record.

See: Kerr, R.A. 2002. Could poor nutrition have held life back? *Science*, v. **297**, p. 1104-1105; DOI: 10.1126/science.297.5584.1104.

Isotopic evidence for early life may be from metamorphic processes (August 2002)

Controversy has surrounded reports of carbon-isotope evidence from the oldest recognisable sedimentary rocks that can be interpreted as signs of life 3800 Ma ago. The problem is that the data came from carbon trapped in resistant minerals, such as apatite, in the metamorphosed Isua supracrustal rocks of west Greenland. A detailed study of carbon in various forms in the Isua metasediments (van Zullen, M.A. *et al.* 2002. [Reassessing the evidence for the earliest traces of life](#). *Nature*, v. **418**, p. 627-630; DOI: 10.1038/nature00934) strongly suggests that the isotopic evidence for life is flawed. It seems likely that both graphite and carbonates in the Isua rocks originated by chemical reactions that took place during metamorphism; they are probably metasomatic in origin. The wide range of $\delta^{13}\text{C}$ values found in both graphites and carbonates could have formed by isotopic exchange between graphite and carbonate during metamorphism. Graphite inclusions in apatite, the source of carbon isotopes claimed to reflect the earliest biological activity, are petrographically no different from inclusions in other minerals. Indeed, the sample originally used to suggest the isotopic influence of early life is of metasomatic origin.

All is not lost, however, for graphite that is highly depleted in heavy carbon-13 (a sign, albeit ambiguous, for organic processes) also occurs in turbidites that show graded bedding. These rocks show no petrographic signs of metasomatism, and may contain signs of life. Ominously, the US, Norwegian and Estonian co-workers, having looked in detail at carbon found in low concentration within BIFs and cherts from Isua, conclude that at least some is recent organic matter that groundwater flow has carried into the rocks.

Conodonts and late Devonian mass extinction (September 2002)

The Late Devonian saw sufficient extinctions (around 55 % of all genera) for it to rank among the Big Five, but most genera that disappeared were shallow-water marine, particularly rugose and tabulate corals. Although the Woodleigh impact structure, just north of Perth in Western Australia, has been suggested as a possible culprit, its age is not reliable. Another

possible cause is climatic cooling at low-latitudes, because the extinction was followed by the spread to tropical localities of high-latitude faunas. The key to supporting a climatic influence is temperature data from areas most affected by the extinctions. Unusually, a recent study selected phosphatic [conodonts](#) (tooth-like microfossils) for oxygen-isotope investigations - carbonate-shelled creatures are the usual choice. Michael Joachimski and Werner Buggisch, of the University of Erlangen in Germany, found prominent oxygen isotope excursions close the Frasnian-famenian boundary (Joachimski, M.M & Buggisch, W. 2002. [Conodont apatite \$\delta^{18}\text{O}\$ signatures indicate climatic cooling as a trigger of the Late Devonian mass extinction](#). *Geology*, v. **30**, p. 711-714; DOI: 10.1130/0091-7613(2002)030<0711:CAOSIC>2.0.CO;2). Their data are well controlled stratigraphically, because the rapid evolution of conodonts in the Devonian allows fine biostratigraphic division.



Selection of conodonts (Credit: [Natural History Museum](#), London)

The extinction event is bracketed by two episodes of sea-surface cooling, estimated to involve a drop of 6°C from an otherwise constant ambient temperature of around 32°C. They coincide with significant positive shifts in $\delta^{13}\text{C}$ of seawater, interpreted by the authors as evidence of the burial of much organic carbon debris. Therein lies a possible cause for the cooling. Carbon burial would have drawn down atmospheric CO_2 levels. The extinction does seem to have been a response to temperature stress, tallying with the colonization of low-latitude seas by high-latitude faunas. However, that still begs the question of why carbon burial underwent two spurts. Was there an increase in sediment supply to the oceans that might augment burial rates, or are the positive carbon-isotope excursions reflections of the extinctions themselves? The second still leaves open the possibility that the undoubted cooling events may have had other causes, such as an increase in stratospheric aerosols, resulting either from major explosive volcanism or perhaps impacts that are yet to be found.

Land plants at the P-Tr boundary (October 2002)

The Permian to Triassic transition involved a transformation from globally cool conditions to a hothouse, as well as the largest mass extinction in the fossil record. It also spanned a time when most continental lithosphere was clumped in the Pangaea supercontinent. In the case of plants, it is not easy to sort the effects of climatic shifts from those due to catastrophic events, either the effects of the huge Siberian flood-basalt event (see [Flood basalts of Siberian Traps doubled at a stroke](#) in *Magmatism* 2002) or a yet to be proven impact.

McAllister Rees of the University of Chicago has painstakingly organised global Permian and Triassic floral data to see if the changes were slow (climatically influenced) or sudden (possible evidence for a catastrophic collapse), and if they coincide from region to region. He found that in some regions big changes happened quickly around the P-Tr boundary, but in others the shifts were protracted and unrelated to faunal extinctions (Rees, P. McA. 2002. [Land-plant diversity and the end-Permian mass extinction](#). *Geology*, v. **30**, p. 827-830; doi: 10.1130/0091-7613(2002)030<0827:LPDATE>2.0.CO;2). This clearly implies caution in the interpretation of detailed local records as signs of massive events, and also points out the need to place such records in the contexts of global climate belts and biases that result from varied degrees of biotic preservation.

Dinosaurs did urinate (*October 2002*)

News is coming in of a startling find along a dinosaur trackway in Colorado. At the October meeting of the [Society of Vertebrate Palaeontology](#), Katherine McCarville of the South Dakota School of Mines and Technology described a bath-sized pit preserved among sauropod footprints. Seemingly, all the evidence points to it having been excavated by a gargantuan stream of liquid pouring from above. Ranking as a candidate for the IgNobel Awards of 2003, this evidence for dinosaurian bladder relief may shake the theory that birds are descended from dinosaur ancestors; very few birds urinate.

Continents colonised a billion years ago (*October 2002*)

The Torridonian of NW Scotland is a thick sequence of mainly terrestrial sediments that accumulated on the Laurentian craton, between 1200 and 1000 Ma ago. Much of the sequence evidences braided-stream deposition, with brief lacustrine episodes. Any geologist who examines these mainly siliciclastic rocks will find abundant evidence for subaerial conditions in the form of desiccation cracks, often affecting directional current ripples. However, it takes a keen eye and some knowledge of biofilms to spot any signs of microbial activity. In sandstones they manifest themselves by having increased the normally very low cohesiveness of wet sand by their binding action (Prave, A.R. 2002. Life on land in the Proterozoic: evidence from the Torridonian rocks of northwest Scotland. *Geology*, v. **30**, p. 811-814; doi: [10.1130/0091-7613\(2002\)030<0811:LOLITP>2.0.CO;2](#)). Prave analysed the shapes of desiccation polygons to show that the Torridonian sands were unusually cohesive, and recognised other features likely to have been formed by microbial crusts. These finds add to the growing evidence for substantial terrestrial biomass, long before the “official” colonisation by land plants in the Silurian and Devonian. Whether or not such an expansion of the biosphere added significantly to carbon burial and drawdown of atmospheric CO₂, as it did in post-Silurian times, remains to be determined from average carbon contents of quite rare Precambrian terrestrial sediments,

Mitochondria, oxygen toxicity and the quahog (*November 2002*)

One of the many crises through which life passed during its evolution was the widespread appearance of oxygen. This occurred once the release of soluble iron-2 to the oceans from sea-floor processes fell below a rate that buffered the photosynthetic generation of oxygen

through the precipitation of iron-3 oxides in marine sediments. Oxygen is life-threatening, largely through its encouraging the formation of simple compounds that are more potent oxidizers than oxygen (O₂) itself, such as O⁻, H₂O₂ and HO. In cells they can lead to genetic degeneration, progressive ageing and eventually cell death. Free oxygen in the environment was a stealthy threat to all life forms that existed around 2200 Ma. A possible evolutionary response that may have opened the way for the later rise of the Eucarya, and the huge diversification that permitted, is nicely summarized by Doris Abele in *Nature* of 7 November 2002 (Abele, D. 2002. [The radical life-giver](#). *Nature*, v. **420**, p. 27; DOI: 10.1038/420027a). The main strand of her argument is that mitochondria, the energy converters in eukaryote cells, also serve to keep oxygen levels inside cells high enough for metabolism, yet low enough to minimise the formation of threatening oxidants. Her object of study has been the noble ocean quahog, *Arctica islandica* (incidentally, a clam often referred to by Herman Melville in *Moby Dick*) which mysteriously burrows into anoxic muds for a while and drops its metabolism alarmingly. By this habit, the quahog has achieved what middle-aged Californians yearn for; spectacular life extension to as much as 220 years. Abele believes that this protective function of mitochondria is deployed by the quahog, having arisen in the earliest Eucarya, after the oxygenation of the planet. However, as Lyn Margulis observed in developing her endosymbiotic hypothesis for the emergence of eukaryotes, mitochondrial RNA is very like that of oxygen-respiring purple bacteria. Anti-oxidant mechanisms may therefore be more ancient. The other main defence against free radicals takes the form of a range of vitamins and other complex compounds, some of which seem to have their origins in heat-shock proteins; possibly harking back to life's origins near deep-ocean hydrothermal vents.

In a similar vein, linked to the rise of oxygen concentrations, doubt has been cast on the role of photosynthesising cyanobacteria since the earliest times.. Most geologists hold them responsible for creating stromatolites since 3500 Ma, and also for providing an early source of oxygen that was rapidly scavenged by the precipitation of iron oxides in banded iron formations. Carrine Blank, a palaeobiologist at Washington University in St Louis, has genetically compared cyanobacteria with a range of other living Bacteria, to assess their relatedness. Her work suggests that the blue-greens were late additions to early life, perhaps long after the first BIFs appeared.

A possible fuse for the Cambrian Explosion (*December 2002*)

The sudden appearance of shelly fossils between about 544 to 542 Ma is the most astonishing feature of biological evolution, especially as representatives of every modern animal phylum (and some which have vanished) appear at that time. A means to explain this short-lived blossoming has eluded palaeontologists. Part of the problem is that the record of the immediately preceding Neoproterozoic Era cannot resolve whether the phyla sprang up at the same time as they developed hard parts, or had been evolving as flaccid forms for much longer. Another aspect is the difficulty in accounting for the sudden adoption of calcium carbonate and phosphate hard parts. It seems inescapable that the issue of hard parts, which is really what the "Explosion" is all about, cannot be separated from the chemistry of seawater at the time.

A new insight into what was going on was presented at the October GSA meeting in Denver by John Grotzinger and colleagues at MIT, who have been examining drill cores through the

Precambrian-Cambrian boundary beneath the south Omani oil fields (Amthor J.E. *et al.* 2003. [Extinction of Cloudina and Namacalathus at the Precambrian-Cambrian boundary in Oman](#). *Geology*, v. **31**, p. 431-434; 10.1130/0091-7613(2003)031<0431:EOCANA>2.0.CO;2). The Late Neoproterozoic basin in which the deposits began to form was a semi-enclosed basin, dominated by stromatolitic carbonates. Seawater in it contained excess calcium and carbonate ions. Periodically, the basin was cut off and evaporites began to form; it became hypersaline. In the cyclical sequence the very earliest carbonate-shelled organisms (*Cloudinia* and *Namacalathus*) left fossil remains. However, in cycles of earliest Cambrian age they simply disappear, not merely in Oman but world wide. Moreover, rocks from which they are missing show abnormally light $\delta^{13}\text{C}$, generally interpreted as a result of mass extinction. The demise of two organisms, albeit the only ones that could have left any record, may not seem very dramatic. But Grotzinger and colleagues suggest that a sudden extinction could mark a critical period in evolution that both reduced the population of all organisms and sterilised ecological niches for future adaptive radiation. Interesting, but still not explaining why hard parts were adopted to become so very necessary in subsequent animal evolution.

Source: Kerr, R.A. A trigger for the Cambrian Explosion? *Science*, v. **298**, p. 1547; DOI: 10.1126/science.298.5598.1547.