Palaeontology, palaeobiology and evolution

Land almost colonized during the Cambrian Explosion (January 2014)

One of the major shale-gas source strata in the eastern USA, the Middle Cambrian Conasauga Shale, formed in a shallow inland sea. Consequently the lowest Palaeozoic sedimentology of the region and the strange structures that affected it during deformation that formed the Appalachian Mountains have become a focus of intense tectonic and stratigraphic interest. Economic potential generally helps fund academic research at a time when money for pure science is short. This has extended into the deepest part of the Cambrian lying unconformably just above the crystalline Precambrian basement. The Lower Cambrian of the Appalachians marks the earliest stage of rifting that flooded former dry land and comprises the multicoloured mudstones, siltstones and sandstones of the Rome Formation. Though only sparsely fossiliferous, the Rome Formation contains archetypical trilobites of the genus *Olenellus*, typical of the Lower Cambrian and used to correlate sedimentary rocks of this age far and wide. They occur across the North Atlantic in coeval rocks of the Northwest Highlands of Scotland, but not in those a mere couple of hundred kilometres to the south in Wales. This faunal disparity forms a major line of evidence that the olenellid fauna occupied one side of a once major ocean – Iapetus – another different bunch of early trilobites being characteristic of its opposite flank. The almost hemispherical extent of similar faunas was long regarded as an indication that they inhabited open ocean water. In fact, their wide distribution is as much due to juvenile arthropods being planktonic, while adults may have occupied all sorts of marine environments. It now turns out that *Olenellus* lived in very shallow water (Mángano, M.G. et al. 2014. *Trilobites in early Cambrian tidal flats and the landward expansion of the Cambrian explosion*. *Geology*, v. 42, p. 146-146: DOI: 10.1130/G34980.1).

![Sketch of Olenellus thompsoni](image)

Gabriela Mángano of the University of Saskatchewan and colleagues from Argentina and the US found that the Rome Formation is full of sedimentary structures typical of modern
intertidal zones. Tidal-flat strata show abundant sun cracks but are also criss-crossed by tracks made by substantial arthropods, only fossil olenellid trilobites being big enough to have made them while feeding, maybe on microbial mats formed on the mudflats or on worms that burrowed the muds. Clearly these animals were literally only a few steps away from colonising the land very shortly after abundant, sturdy animal life appeared in the Cambrian Explosion. Currently the dominant hypothesis for permanent entry of animals onto land is that the colonizers first adapted to fresh- or brackish water habitats. Yet, apparently, there was little to stop a direct invasion from the sea.

Plate tectonics and the Cambrian Explosion (January 2014)

A rough-and-ready way of assessing the rate at which silicic magmatic activity has varied through time is to separate out grains of zircon that have accumulated in sedimentary rocks of different ages. Zircon is readily datable using the U-Pb method, if you have access to mass spectrometry. While some of the zircons will date from much older continental crust that was exposed while the sediments originated, sometimes there are grains that formed only a few million years before the sediments accumulated. Those are likely to have crystallized from silica-rich volcanic rocks above subduction zones where ocean-floor has been driven beneath continental crust; i.e. at continental volcanic arcs. Such young zircons therefore help assess the tectonic conditions close to sedimentary basins. The potential of detrital zircon geochronology was first suggested to me by Dr M.V.N. Murthy of the Geological Survey of India in 1978, long before anyone could aspire to mass zircon dating. M.V.N. had by then amassed kilograms of zircon grains from every imaginable source in India, and may have been the first geologist to realise their potential. It has become a lot quicker and cheaper in the last two decades, thanks to methods of dating single zircon grains both precisely and accurately and M.V.N.’s prescient suggestion has been borne out globally.

Results for the late Precambrian to early Palaeozoic have recently been compiled (McKenzie, N.R. et al. 2014. Plate tectonic influences on Neoproterozoic-early Paleozoic climate and animal evolution, Geology, v. 42, p. 127-30; DOI: 10.1130/G34962.1). One of the striking correlations is between the abundance of ‘young’ zircons relative to Cambrian
sedimentary deposition and the pace of diversification of animal faunas during the Cambrian. There may have been far more continental-margin arc volcanism than in the preceding late Neoproterozoic or later in the early Palaeozoic. That would match with evidence for the Cambrian atmosphere having reached the greatest CO₂ concentration of Phanerozoic times and the fact that the Gondwana supercontinent (comprising the present southern continents plus India) was assembled at that time by collision of several Precambrian continental masses. Global temperatures must have been rising.

Earth at the start of the Cambrian showing the cratons that collided to form Gondwana

The Cambrian Explosion of all the major animal groups by the middle Cambrian took place during and despite climatic warming. Environmental stress, perhaps increased calcium and bicarbonate ions in sea water as a result of acid conditions, may have forced animals to develop means of getting both ions out of their cells to form carbonate skeletons: the Cambrian Explosion really marks the first appearance of abundant shelly faunas and thereby a good chance of fossilisation. Yet at the peak of volcanically-induced warming, faunal diversity, especially of reef-building animals, fell-off dramatically to create what some palaeobiologists have termed the Cambrian ‘dead interval’. Marine life really took-off in a big way during the Ordovician while temperatures were falling globally; so much so that the close of the Ordovician was marked by the first major glaciation, focused on Gondwana. The zircon record indicates that continental-arc volcanism also declined during the Ordovician, and maybe the Cambrian silicic volcanics were chemically weathered during that Period to remove carbon-dioxide from the atmosphere, along with renewed reef building to bury carbonate fossils.

Cambrian Explosion reviewed (March 2014)

To set against five brief episodes of mass extinction – some would count the present as being the beginning of a sixth – is one short period when animals with hard parts appeared for the first time roughly simultaneously across the Earth. Not only was the Cambrian
Explosion sudden and pervasive but almost all phyla, the basic morphological divisions of multicellular life, adopted inner or outer skeletons that could survive as fossils. Such an all-pervading evolutionary step has never been repeated, although there have been many bursts in living diversity. Apart from the origin of life and the emergence of its sexual model, the eukaryotes, nothing could be more important in palaeobiology than the events across the Cambrian-Precambrian boundary.

A Cambrian evolutionary experiment: *Opabinia regalis* from the Burgess Shale

This eminent event has been marked by most of the latest issue of the journal *Gondwana Research* (volume 25, Issue 3 for April 2014) in a 20-paper series called Beyond the Cambrian Explosion: from galaxy to genome (summarized by Isozaki, Y. et al. 2014. Beyond the Cambrian Explosion: from galaxy to genome. *Gondwana Research*; v. 25, p. 881-883; DOI: 10.1016/j.gr.2014.01.001). These phenomenal events have been at issue since the 19th century when the division of geological time began to be based on the appearance and vanishing of well preserved and easily distinguished fossils in the stratigraphic column. On this basis roughly the last ninth of the Earth’s history was split on palaeontological grounds into the 3 Eras, 11 Periods, and a great many of the briefer Epochs and Ages that constitute the Phanerozoic. Time that preceded the Cambrian explosion was for a long while somewhat murky mainly because of a lack of means of subdivision and the greater structural and metamorphic damage that had been done to the rocks that had accumulated over 4 billion years since the planet accreted.

Detail emerged slowly through increasingly concerted study of the Precambrian, helped since the 1930s by the ability to assign numerical ages to rocks. Signs of life in sediments that had originally been termed the Azoic (Greek for ‘without life’) gradually turned up as far back as 3.5 Ga, but much attention focused on the 400 Ma immediately preceding the start of the Cambrian period once abundant trace fossils had been found in the Ediacaran Hills of South Australia that had been preceded by repeated worldwide glacial epochs. The Cryogenian and Ediacaran Periods (850-635 and 635-541 Ma respectively) of the Neoproterozoic figure prominently in 9 of the papers to investigate or review the ‘back story’ from which the crucial event in the history of life emerged. Six have a mainly Cambrian focus on newly discovered fossils, especially from a sedimentary sequence in southern China that preserves delicate fossils in great detail: the Chengjian Lagerstätte.
Others cover geochemical evidence for changes in marine conditions from the Cryogenian to Cambrian and reviews of theories for what triggered the great faunal change.

Since the hard parts that allow fossils to linger are based on calcium-rich compounds, mainly carbonates and phosphates that bind the organic materials in bones and shells, it is important to check for some change in the Ca content of ocean water over the time covered by the discourse. In fact there are signs from Ca-isotopes in carbonates that this did change. A team of Japanese and Chinese geochemists drilled through an almost unbroken sequence of Ediacaran to Lower Cambrian sediments near the Three Gorges Dam across the Yangtse River and analysed for $^{44}$Ca and $^{42}$Ca (Sawaki, Y. et al. 2014. The anomalous Ca cycle in the Ediacaran ocean: Evidence from Ca isotopes preserved in carbonates in the Three Gorges area, South China. *Gondwana Research*, v. 25, p. 1070-1089; DOI: 10.1016/j.gr.2013.03.008) calibrated to time by U-Pb dating of volcanic ash layers in the sequence (Okada, Y. et al. 2014. New chronological constraints for Cryogenian to Cambrian rocks in the Three Gorges, Weng’an and Chengjiang areas, South China. *Gondwana Research*, v. 25, p. 1027-1044; DOI: 10.1016/j.gr.2013.05.001). Sawaki et al. found that there were significant changes in the ratio between the two isotopes. The $^{44}$Ca/$^{42}$Ca ratio underwent a rapid decrease, an equally abrupt increase then a decrease around the start of the Cambrian, which coincided with the $^{87}$Sr/$^{86}$Sr isotope ratios showing a major upward ‘spike’ and then a broad increase in in the Lower Cambrian. The authors ascribe this to an increasing Ca ion concentration in sea water through the Ediacaran and a major perturbation just before the Cambrian Explosion, which happens to coincide with Sr-isotope evidence for a major influx of isotopically old material derived from erosion of the continental crust. As discussed in *Origin of the arms race* (May 2012) perhaps the appearance of animals’ hard parts did indeed result from initial secretions of calcium compounds outside cells to protect them from excess calcium’s toxic effects and were then commandeered for protective armour or offensive tools of predation.

![Artist’s impression of a Snowball Earth event 640 Ma ago](Credit: guano via Flickr)

Is there a link between the Cambrian Explosion and the preceding Snowball Earth episodes of the Cryogenian with their associated roller coaster excursions in carbon isotopes? Xingliang Zhang and colleagues at Northwest University in Xian, China (Zhang, X.
et al. 2014. *Triggers for the Cambrian explosion: Hypotheses and problems.* *Gondwana Research*, v. 25, p. 896-909; DOI: 10.1016/j.gr.2013.06.001) propose that fluctuating Cryogenian environmental conditions conspiring with massive nutrient influxes to the oceans and boosts in oxygenation of sea water through the Ediacaran set the scene for early Cambrian biological events. The nutrient boost may have been through increased transfer of water from mantle to the surface being linked to the start of subduction of wet lithosphere and expulsion of fluids from it as a result of the geotherm cooling through a threshold around 600 Ma (Maruyama, S. *et al.* 2014. *Initiation of leaking Earth: An ultimate trigger of the Cambrian explosion.* *Gondwana Research*, v. 25, p. 910-944; DOI: 10.1016/j.gr.2013.03.012). Alternatively the nutrient flux may have arisen by increased erosion as a result of plume-driven uplift (Santosh, M. *et al.* 2014. *The Cambrian Explosion: Plume-driven birth of the second ecosystem on Earth.* *Gondwana Research*, v. 25, p. 945-965; DOI: 10.1016/j.gr.2013.03.013).

A bolder approach, reflected in the title of the Special Issue, seeks an interstellar trigger (Kataoka, R. *et al.* 2014. *The Nebula Winter: The united view of the snowball Earth, mass extinctions, and explosive evolution in the late Neoproterozoic and Cambrian periods.* *Gondwana Research*, v. 25, p. 1153-1163; DOI: 10.1016/j.gr.2013.05.003). This looks to encounters between the Solar System and dust clouds or supernova remnants as it orbited the galactic centre: a view that surfaces occasionally in several other contexts. Such chance events may have been climatically and biologically catastrophic: a sort of nebular winter, far more pervasive than the once postulated nuclear winter of a 3rd World War. That is perhaps going a little too far beyond the constraints of evidence, for there should be isotopic and other geochemical signs that such an event took place. It also raises yet the issue that life on Earth is and always has been unique in the galaxy and perhaps the known universe due to a concatenation of diverse chance events, without structure in time or order, which pushed living processes to outcomes whose probabilities of repetition are infinitesimally small.

**The Higgs boson, gravity waves and now... dark matter and the dinosaurs (March 2014)**

The discovery around 50 years ago that in orbiting the centre of the Milky Way galaxy the solar system regularly wobbles to either side of its path. If the galaxy’s physical properties varied in a direction at right angles to the plane of the Milky Way then the Sun and its planets would experience that variation in a regular and predictable way (see *Galactic controls* Palaeoclimatology January 2011). Such oscillations might therefore show up as periodic changes in the geological record. There are loads of such cycles some not so regular, such as the accretion and disaggregation of supercontinents, and some involved in climatic change that have almost the predictability of a metronome.

One of these periodicities has thrilled some geoscientists ever since it first began to emerge from improved dating of events in the geological record and more extensive knowledge of what it contained. Massive floods of basaltic magma blurt from the mantle every so often; more specifically approximately every 35 Ma. Intriguingly, there is a rough tally between the timing of such large igneous provinces and pulses in biological extinction. The wobbles in the solar system’s galactic passage are – wait for it – about every 35 Ma. A supposed link between LIPs, extinctions and galactic motions simply will not go away as a topic for speculation. Add to that some evidence that terrestrial impact cratering might have a 35 Ma period and you have ‘a story that will run and run’. The apparent periodicity of impacts,
besides fostering links with life and death and magmas, now seems to have spurred links with the *dark side of cosmology*.

![Artist’s conception of the spiral structure of the Milky Way with two major stellar arms and a central bar](image)

It does indeed seem that the galactic magnetic field and dust concentrations vary across the plane of the Milky Way, but their affects during solar peregrinations have been raised long before now (Steiner, J. 1967. *The sequence of geological events and the dynamics of the Milky Way Galaxy*. *Journal of the Geological Society of Australia*, v. 14, p. 99–132; DOI: 0.1080/00167616708728648). The latest novelty concerns the possibility that galaxies might somehow collect the fabled but as yet undiscovered *‘dark matter’* in a flat disc within the *galactic plane*. Well, matter, ‘dark’ or not, should have mass, and mass must have a gravitational effect (thanks of course to the Higgs boson), even if it is hidden. Instead of some Nemesis or Death Star, as once was proposed to nudge comets from the outer reaches of the solar system, a gigantic dish of dark matter through which the Sun might pass on a regular basis might serve more plausibly (Randall, L. & Reece, MM. 2014. *Dark matter as a trigger for periodic comet impacts*. *Physical Review Letters*, v. 112, 161301; DOI: 10.1103/PhysRevLett.112.161301). Interestingly, Comments on the paper at the arXiv site read “Accepted by Physical Review Letters. 4 figures, no dinosaurs”

![Solar System in Perspective (credit: NASA Goddard SFC)](image)

**Related article:** *Did dark matter help kill off the dinosaurs?* (physicsworld.com)
Update on giant fossil squirrel (April 2014)

Eleven years on from his announcement in March 2003 of a giant member of the Family Sciuridae (squirrels) found in a lateritic lagerstätte in the Western Ghats of Karnataka State in India (see Squirrels and tectonics March 2003) Professor Pandit U. Siffli emeritus at the Sringeri Institute of Palaeontology has sent me further news of his investigations. The clay-filled pocket within the mottled zone has proved astonishingly fruitful now that Pandit Unmer has more free time following his retirement. He and his recently graduated colleague, Dr G.B. Harm, have unearthed several more exquisite specimens of Titanosciurus sringeriensis – readers will recall that the body cavity of the child-sized type specimen of T. sringeriensis contained bones of primitive hamsters, that no doubt the squirrel had consumed, confirming Siffli’s speculation that the creature was the only known member of the Sciuridae that was an obligate carnivore. This view stemmed originally from its formidable dentition.

Confirmation of this astounding revelation comes from two new lines of evidence discovered by Dr Harm; the principle excavator since Prof Siffli became encumbered by what he has described to me as his ‘blessed game leg’. In his letter he says, ‘young Grivas Bodili has informed me in a mood of solemn gaiety that there are burrows in the lagerstätte which contain complete skeletons of hamsters in a cowering posture. There are also abundant coprolites associated with one of the more corpulent specimens of T. sringeriensis that are a rich source of tiny hamster bones and one example of a partly digested avian flight feather’. The pair now have a paper in press (Harm, G.B. & Siffli, P.U. in press 2014. A large predatory sciurid from the Kudremukh laterites, Karnataka, India: evidence from a well-preserved rodent warren. Earth and Sanitary Appliance Letters, DOI: 11.3319/esal55164).

It seems likely that the squirrels and hamsters burrowed into the laterite soon after intense tropical weathering has ceased due to climatic cooling associated with the onset of glaciation in Antarctica, probably in late-Eocene times. At that stage the upper laterite must have been soft enough for early mammals to dig into it. Subsequently the palaeosol became indurated as a result of regional desiccation, allowing exquisite preservation. Exact dating by the Ar-Ar method may soon be possible, given samples containing potassium-rich authigenic

Laterite (credit: Paul J. Morris)
minerals. The search is now surely on for similar subterranean lagerstätten in the lateritic veneers covering vast tracts of the southern continents, whose formation probably came to a close at roughly the same time as did those of South India.

![Artist’s impression of T. sringeriensis with hamster (credit: network54.com)](image)

Prof Siffli tells me he would welcome communications from other sciurid and laterite researchers at pusifli@gmail.com

**Oxygen, magnetic reversals and mass extinctions (April 2014)**

Nine years ago I reported evidence for a late Permian fall in atmospheric oxygen concentration to about 16% from its all-time high of 30% in the Carboniferous and earlier Permian (see [New twist for end Permian extinctions](April 2005)). This would have reduced the highest animal-habitable elevation on land to about 2.7 km above sea level, compared with 4 to 5 today. Such an event would have placed a great deal of stress on terrestrial animal families. Moreover, it implies anoxic conditions in the oceans that would stress marine animals too. At the time, it seemed unlikely that declining oxygen was the main trigger for the end-Permian mass extinction as the decline would probably have been gradual, for instance by oxygen being locked into iron-3 compounds that give Permian and Triassic terrestrial sediments their unrelenting red coloration. By most accounts, the greatest mass extinction of the Phanerozoic was extremely swift.

The possibility of extinctions being brought on by loss of oxygen from the air and ocean water has reappeared, with suggestions of a very different means of achieving it (Wei, Y. and 10 others 2014. *Oxygen escape from the Earth during geomagnetic reversals: Implications to mass extinction*. *Earth and Planetary Science Letters*, v. 394, p. 94-98; DOI: 10.1016/j.epsl.2014.03.018). The nub of the issue proposed by the Chinese-German collaborators is the dissociation and ionization by solar radiation of O₂ molecules into O⁺ ions. If exposed to the solar wind in the upper stratosphere, such ions could literally be ‘blown away’ into interplanetary space; one explanation for the lack of much in the way of any atmosphere on Mars today. Mars is prone to such ionic ablation because it now has a very weak magnetic field and may have been in that state for 3 billion years or more. Earth’s much larger magnetic field diverts the solar wind by acting as an electromagnetic buffer against much loss of gases, except free hydrogen and, to a lesser extent, helium. But the
geomagnetic field undergoes reversals, and while they are in progress, the field drops to very low levels. That may expose Earth to loss of oxygen as well as to dangerous levels of ionising radiation through unprotected exposure of the surface to the solar wind.

Field reversals and, presumably, short periods of very low geomagnetic field associated with them, varied in their frequency through time. For the past 80 Ma the reversal rate has been between 1 and 5 per million years. For much of the Cretaceous Period there were hardly any during a magnetic quiet episode or superchron. Earlier Mesozoic times were magnetically hectic, when reversals rose to rates as high as 7 per million years in the early Jurassic. This was preceded by another superchron that spanned the Permian and Late Carboniferous. Earlier geomagnetic data are haphazardly distributed through the stratigraphic column, so little can be said in the context of reversal-oxygen-extinction connections.

Geo magnetic polarity over the past 169 Ma

Wei et al. focus on the end-Triassic mass extinction which does indeed coincide, albeit roughly, with low geochemically modelled atmospheric oxygen levels (~15%). This anoxic episode extended almost to the end of the Jurassic, although that was a period of rapid faunal diversification following the extinction event. Yet it does fall during the longest period of rapid reversals of the Mesozoic. However, this is the only clear reversal-oxygen-extinction correlation, the Cenozoic bucking the prediction. In order to present a seemingly persuasive case for their idea, the authors assign mass extinctions not to very rapid events – of the order of hundreds of thousand years at most – which is well supported by both fossils and stratigraphy, but to ‘blocks’ of time of the order of tens of million years.

My own view is that quite possibly magnetic reversals can have adverse consequences for life, but as a once widely considered causal mechanism for mass extinction they have faded from the scene; unlikely to be resurrected by this study. There are plenty of more plausible
and better supported mechanisms, such as impacts and flood-basalt outpourings. Yet several large igneous provinces do coincide with the end of geomagnetic superchrons, although that correlation may well be due to the associated mantle plumes marking drastic changes around the core-mantle boundary. According to Wei et al., the supposed 6th mass extinction of the Neogene has a link to the general speeding up of geomagnetic reversals through the Cenozoic: not much has happened to either oxygen levels or biodiversity during the Neogene, and the predicted 6th mass extinction has more to do with human activity than the solar wind.

How the first metazoan mass extinction happened (May 2014)
The end-Ordovician mass extinction was the first of five during the Phanerozoic. It happened in two distinct phases that roughly coincided with an intense but short-lived glaciation at the South Pole, then situated within what is now the African continent. Unlike the other four major extinctions, this biotic catastrophe seems unlinked to either a major impact structure or to an episode of flood volcanism.

Artist’s impression of an Ordovician shallow-sea community (credit: drtel)
In March 2009 I noted in Possible effects of a mid-Ordovician bombardment a curious occurrence in 470 Ma (Darriwilian Stage) Swedish limestones. They contain a large number of altered chondritic meteorites, possible evidence that there may have been an extraterrestrial influence on extinction rates around that time. In support, there is evidence that the Ordovician meteorite swarm coincided with megabreccias or olistostromes at what were then Southern Hemisphere continental margins: possible signs of a series of huge tsunamis. But in fact this odd coincidence occurred at a time when metazoan diversity was truly booming: possibly the only known case of impacts having a beneficial aspect.

Number One of the Big Five mass extinctions occurred during the late-Ordovician Hirnantian stage (443-445 Ma) and has received much less attention than the later ones. So it is good to see the balance being redressed by a review of evidence for it and for possible mechanisms (Harper, D.A.T et al. 2014. End Ordovician extinctions: A coincidence of causes. Gondwana Research, v. 25, p. 1294-1307; DOI: 10.1016/j.gr.2012.12.021). The first event of
a double-whammy that mainly affected free-swimming and planktonic organisms and those of shallow seas; near-surface dwellers such as graptolites and trilobites. The second, about a million years later, hit animals living at all depths in the sea. Between them, the two events removed about 85% of marine species – there were few if any terrestrial animals so this is close to the extinction level that closed the Palaeozoic at around 250 Ma.

No single process can be regarded as the ‘culprit’. However the two events are bracketed by an 80-100 m fall in sea level due to the southern hemisphere glaciation. That may have given rise to changes in ocean oxygen content and in the reduction of sulfur to hydrogen sulfide. Also there may have been changes in the vertical, thermohaline circulation of the oceans, falling temperatures encouraging sinking of surface water to abyssal depths providing more oxygen to support life deep in the water column. Sea-level fall would have reduced the extent of shallow seas too. Those consequences would explain the early demise of shallow water, free-swimming animals. Reversal of these trends as glaciation waned may have returned stagnancy and anoxia to deep water, thereby affecting life at all depths. The authors suggest generalized ‘tipping points’ towards which several global processes contributed.

Nickel, life and the end-Permian extinction (June 2014)

The greatest mass extinction of the Phanerozoic closed the Palaeozoic Era at the end of the Permian, with the loss of perhaps as much as 90% of eukaryote diversity on land and at sea. It was also over very quickly by geological standards, taking a mere 20 thousand years from about 252.18 Ma ago. There is no plausible evidence for an extraterrestrial cause, unlike that for the mass extinction that closed the Mesozoic Era and the age of dinosaurs. Almost all researchers blame one of the largest-ever magmatic events that spilled out the Siberian Traps either through direct means, such as climate change related to CO₂, sulfur oxides or
atmospheric ash clouds produced by the flood volcanism or indirectly through combustion of coal in strata beneath the thick basalt pile. So far, no proposal has received universal acclaim. The latest proposal relies on two vital and apparently related geochemical observations in rocks around the age of the extinctions (Rothman, D.H. et al. 2014. Methanogenic burst in the end-Permian carbon cycle. Proceedings of the National Academy of Sciences, v. 111, p. 5462-5467; DFI: 10.1073/pnas.1318106111).

In the run-up to the extinction carbon isotopes in marine Permian sediments from Meishan, China suggest a runaway growth in the amount of inorganic carbon (in carbonate) in the oceans. The C-isotope record from Meishan shows episodes of sudden major change (over ~20 ka) in both the inorganic and organic carbon parts of the oceanic carbon cycle. The timing of both ‘excursions’ from the long-term trend immediately follows a ‘spike’ in the concentration of the element nickel in the Meishan sediments. The Ni almost certainly was contributed by the massive outflow of basalt lavas in Siberia. So, what is the connection?

Some modern members of the prokaryote Archaea that decompose organic matter to produce methane have a metabolism that depends on Ni, one genus being Methanosarcina that converts acetate to methane by a process known as acetoclastic methanogenesis. Methanosarcina acquired this highly efficient metabolic pathway probably though a sideways gene transfer from Bacteria of the class Clostridia; a process now acknowledged as playing a major role in the evolution of many aspects of prokaryote biology, including resistance to drugs among pathogens. Molecular-clock studies of the Methanosarcina genome are consistent with this Archaea appearing at about the time of the Late Permian. A burst of nickel ‘fertilisation’ of the oceans may have resulted in huge production of atmospheric methane. Being a greenhouse gas much more powerful than CO₂, methane in such volumes would very rapidly have led to global warming. Before the Siberian Traps began to be erupted nickel would only have been sufficiently abundant to support this kind of methanogen around ocean-floor hydrothermal springs. Spread globally by eruption plumes, nickel throughout the oceans would have allowed Methanosarcina or its like to thrive everywhere with disastrous consequences. Other geochemical processes, such as the oxidation of methane in seawater, would have spread the influence of the biosphere-lithosphere ‘conspiracy’. Methane oxidation would have removed oxygen from the oceans to create anoxia that, in turn, would have encouraged other microorganisms that reduce sulfate ions to sulfide and thereby produce toxic hydrogen sulfide. That gas once in the atmosphere would have parlayed an oceanic ‘kill mechanism’ into one fatal for land animals.

There is one aspect that puzzles me: the Siberian Traps probably involved many huge lava outpourings every 10 to 100 ka while the magma lasted, as did all other flood basalt events. Why then is the nickel from only such eruption preserved in the Meishan sediments, and if others are known from marine sediments is there evidence for other such methanogen ‘blooms’ in the oceans?

Mass extinctions’ connections with volcanism: more support (July 2014)
Plot the times of peaks in the rates of extinction during the Mesozoic against those of flood basalt outpourings closest in time to the die-offs and the graph defines a straight line. There is sufficiently low deviation between it and the points that any statistician would agree that the degree of fit is very good. Many geoscientists have used this empirical relationship to
claim that all Mesozoic mass extinctions, including the three largest (end-Permian, end-Triassic and end-Cretaceous) were caused in some way by massive basaltic volcanism. The fact that the points are almost evenly spaced – roughly every 30 Ma, except for a few gaps – has suggested to some that there is some kind of rhythm connecting the two very different kinds of event.

Major Mesozoic extinctions and flood basalt events

Leaving aside that beguiling periodicity, the hypothesis of a flood-basalt – extinction link has a major weakness. The only likely intermediary is atmospheric, through its composition and/or climate; flood volcanism was probably not violent. Both volcanic-induced perturbations settle down quickly in geological terms. Moreover, flood basalt volcanism is generally short-lived (a few Ma at most) and seems not to be continuous, unlike that at plate margins which is always going on at one or another place. The great basalt piles of Siberia, around the Central Atlantic margins and in Western India are made up of individual thick and extensive flows separated by fossil soils or boles. This suggests that magma blurted out only occasionally, and was separated by long periods (10 to 100 ka) of normality. Evidence for the duration of major extinctions, either from stratigraphy and palaeontology or from proxies such as peaks and troughs in the isotopic composition of carbon (e.g. Nickel, life and mass extinction above) is that they too occurred swiftly; in a matter of tens of thousand years. Most of the points on the flood-basalt – extinction plot are too imprecise in the time dimension to satisfy a definite relationship. Opinion has swung behind an instantaneous impact hypothesis for the K-P boundary event rather than one involving the Deccan Traps in India, simply because the best dating of the Deccan suggests extinction seems to have occurred when no flows were being erupted, while the thin impact-related layer in sediments the world over is exactly at the point dividing Cretaceous flora and fauna from those of the succeeding Palaeogene.
Yet no such link to an extraterrestrial factor is known to exist for any other major extinctions, so volcanism seems to be ‘the only game in town’ for the rest. Until basalt dating is universally more precise than it has been up to the present the case is ‘not proven’; but, in the manner of the Scottish criminal law, each is a ‘cold case’ which can be reopened. The previous article hardens the evidence for a volcanic driver behind the greatest known extinction at the end of the Permian Period. And in short-order, another of the Big Five seems to have been resolved in the same way. A flood basalt province covering a large area of west and north-west Australia (known as the Kalkarindji large igneous province) has long been known to be of roughly Cambrian age, but does it tie in with the earliest Phanerozoic mass extinction at the Lower to Middle Cambrian boundary? New age data suggests that it does at the level of a few hundred thousand years (Jourdan, F. et al. 2014. High-precision dating of the Kalkarindji large igneous province, Australia, and synchrony with the Early-Middle Cambrian (Stage 4-5) extinction. Geology, v. 42, p. 543-546; DOI: 10.1130/G35434.1). The Kalkarindji basalts have high sulfur contents and are also associated with widespread breccias that suggest that some of the volcanism was sufficiently explosive to have blasted sulfur-oxygen gases into the stratosphere; a known means of causing rapid and massive climatic cooling as well as increasing oceanic acidity. The magma also passed through late Precambrian sedimentary basins which contain abundant organic-rich shales that later sourced extensive petroleum fields. Their thermal metamorphism could have vented massive amounts of CO2 and methane to result in climatic warming. It may have been volcanically-driven climatic chaos that resulted in the demise of much of the earliest tangible marine fauna on Earth to create also a sudden fall in the oxygen content of the Cambrian ocean basins.

Breathing spaces or toxic traps in the Archaean ocean (July 2014)

The relationship between Earth’s complement of free oxygen and life seems to have begun in the Archaean, but it presented a series of paradoxes: produced by photosynthetic organisms oxygen would have been toxic to most other Archaean life forms; its presence drew an important micronutrient, dissolved iron-2, from sea water by precipitation of iron-3 oxides; though produced in seawater there is no evidence until about 2.4 Ga for its presence in the air. It has long been thought that the paradoxes may have been resolved by oxygen being produced in isolated patches, or ‘oases’ on the Archaean sea floor, where early blue-green bacteria evolved and thrived.

A stratigraphic clue to the former presence of such oxygen factories is itself quite convoluted. The precipitation of calcium carbonates and therefore the presence of limestones in sedimentary sequences are suppressed by dissolved iron-2: the presence of Fe^{2+} ions would favour the removal of bicarbonate ions from seawater by formation of ferrous carbonate that is less soluble than calcium carbonate. Canadian and US geochemists studied one of the thickest Archaean limestone sequences, dated at around 2.8 Ga, in the wonderfully named Wabigoon Subprovince of the Canadian Shield which is full of stromatolites – bulbous laminated masses probably formed in shallow water from bacterial biofilms (Riding, R. et al. 2014. Identification of an Archean marine oxygen oasis. Precambrian Research, v. 251, p. 232-237; DOI: 10.1016/j.precamres.2014.06.017).
Limestones from the sequence, which stable isotope analyses show to remain unaltered, have abnormally low cerium concentrations relative to the other rare-earth elements. Unaltered limestones from stromatolite-free, deep water limestones show no such negative Ce anomaly. Cerium is the only rare-earth element that has a possible $4^+$ valence state as well as one with lower positive charge that is soluble. So, in the presence of oxygen, cerium can form an insoluble oxide and thus be removed from solution. Cerium thus independently shows that the shallow water limestones formed in seawater that contained free oxygen. Nor was it an ephemeral condition, for the anomalies persist through half a kilometer of limestone.

The study shows that anomalous oxygenated patches existed on the Archaean sea floor, as probably shallow-water basins or shelves isolated by the build up of stromatolite reef barriers. For most prokaryote cells they would have harboured toxic conditions, presenting them with severe chemical stress. Possibly these were the first places where oxygen defence measures evolved, that eventually led to more complex eukaryote cells that not only survive oxygen stress but depend on its presence. That conjecture is unlikely to be fully proved, since the first undoubted fossils of eukaryote cells, known as acritarchs, occur in rocks that are more than 800 Ma years younger.

Related article: *Oxygen oasis for early life found in ancient rock* (New Scientist)