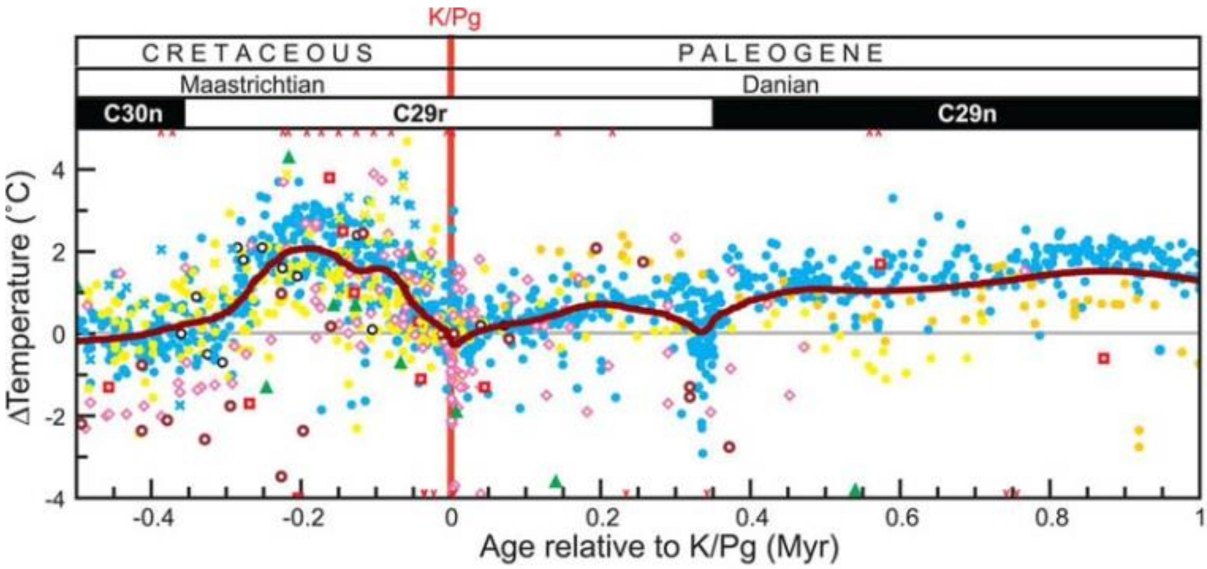
Palaeontology, palaeobiology and evolution (2020)

Closure for the K-Pg extinction event? (January 2020)

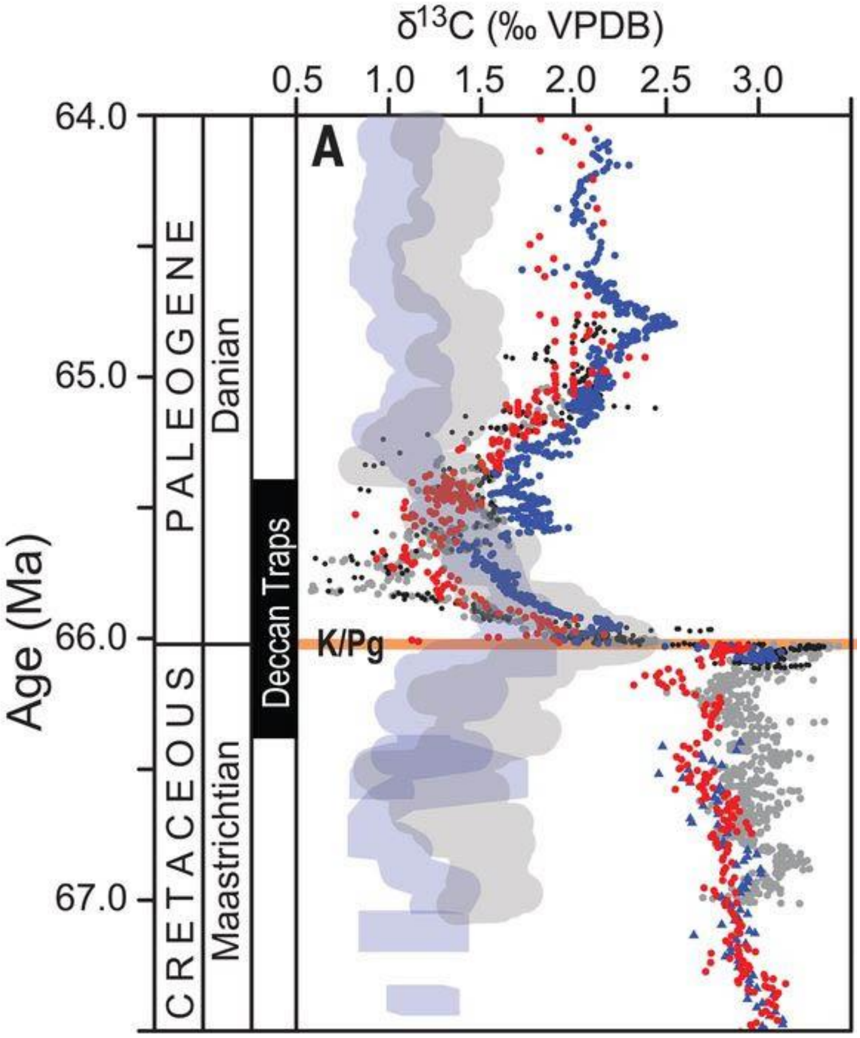
Anyone who has followed the saga concerning the mass extinction at the end of the Cretaceous Period (~66 Ma ago) , which famously wiped out all dinosaurs except for the birds, will know that its cause has been debated fiercely over four decades. On the one hand is the Chicxulub asteroid impact event, on the other the few million years when the Deccan flood basalts of western India belched out gases that would have induced major environmental change across the planet. Support has swung one way or the other, some authorities reckon the extinction was set in motion by volcanism and then 'polished-off' by the impact, and a very few have appealed to entirely different mechanism lumped under 'multiple causes'. One factor behind the continuing disputes is that at the time of the Chicxulub impact the Deccan Traps were merrily pouring out Disentanglement hangs on issues such as what actual processes directly caused the mass killing. Could it have been starvation as dust or fumes shut down photosynthesis at the base of the food chain? What about toxic gases and acidification of ocean water, or being seared by an expanding impact fireball and re-entering incandescent ejecta? Since various lines of evidence show that the late-Cretaceous atmosphere had more oxygen that today's the last two may even have set the continents' vegetation ablaze: there is evidence for soots in the thin sediments that mark the K-Pg boundary. The other unresolved issue is timing: of volcanogenic outgassing; of the impact, and of the extinction itself. A new multi-author, paper may settle the whole issue (Hull, P.M and 35 others 2020. [On impact and volcanism across the Cretaceous-Paleogene boundary](). *Science*, v. **367**, p. 266-272; DOI: 10.1126/science.aay5055).



Marine temperature record derived from $\delta^{18}O$ and Mg/Ca ratios spanning 1.5 Ma that includes the K-Pg boundary: the bold brown line shows the general trend derived from the data points (Credit: Hull et al. 2020; Fig 1)

The multinational team approached the issue first by using oxygen isotopes and the proportion of magnesium relative to calcium (Mg/Ca ratio) in fossil marine shells (foraminifera and molluscs) in several ocean-floor sediment cores, through a short interval spanning the last 500 thousand years of the Cretaceous and the first million years of the

Palaeocene. The first measures are proxies for seawater temperature. The results show that close to the end of the Cretaceous temperature rose to about 2°C above the average for the youngest Cretaceous (the Maastrichtian Age; 72 to 66 Ma) and then declined. By the time of the mass extinction (66 Ma) sea temperature was back at the average and then rose slightly in the first 200 ka of Palaeocene to fall back to the average at 350 ka and then rose slowly again.



Changes in carbon isotopes ($\delta^{13}C$) of bulk carbonate samples from the sediment cores (points) and in deep-water foraminifera (shaded areas) across the K-Pg boundary. (Credit: Hull et al. 2020; Fig 2A)

The second approach was to look in detail at carbon isotopes ($\delta^{13}C$) – a measure of changes in the marine carbon cycle – and oxygen isotopes ($\delta^{18}O$) in deep water foraminifera and bulk carbonate from the sediment cores, in comparison to the duration of Deccan volcanism (66.3 to 65.4 Ma). The $\delta^{13}C$ measure from bulk carbonate stays roughly constant in the Maastrichtian, then falls sharply at 66 Ma. The $\delta^{13}C$ of the deep water forams rises to a peak at 66 Ma. The $\delta^{18}O$ measure of temperature peaks and declines at the same times as it does for the mixed fossils. Also examined was the percentage of coarse sediment grains in the muds from the cores. That measure is low during the Maastrichtian and then rises sharply at the K-Pg boundary.

Since warming seems almost certainly to be a reflection of CO_2 from the Deccan (50 % of total Deccan outgassing), the data suggest not only a break in emissions at the time of the mass extinction but also that by then the marine carbon system was drawing-down its level in air. The $\delta^{13}C$ data clearly indicate that the ocean was able to absorb massive amounts of CO_2 at the very time of the Chicxulub impact and the K-Pg boundary. Flood-basalt eruption may have contributed to the biotic aftermath of the extinction for as much as half a million years. The collapse in the marine fossil record seems most likely to have been due to the effects of the Chicxulub impact. A third study – of the marine fossil record in the cores – undertaken by, presumably, part of the research team found no sign of increased extinction rates in the latest Cretaceous, but considerable changes to the marine ecosystem after the impact. It therefore seems that the K-Pg boundary impact '*had an outsized effect on the marine carbon cycle*'. End of story? As with earlier 'breaks through'; we shall see.

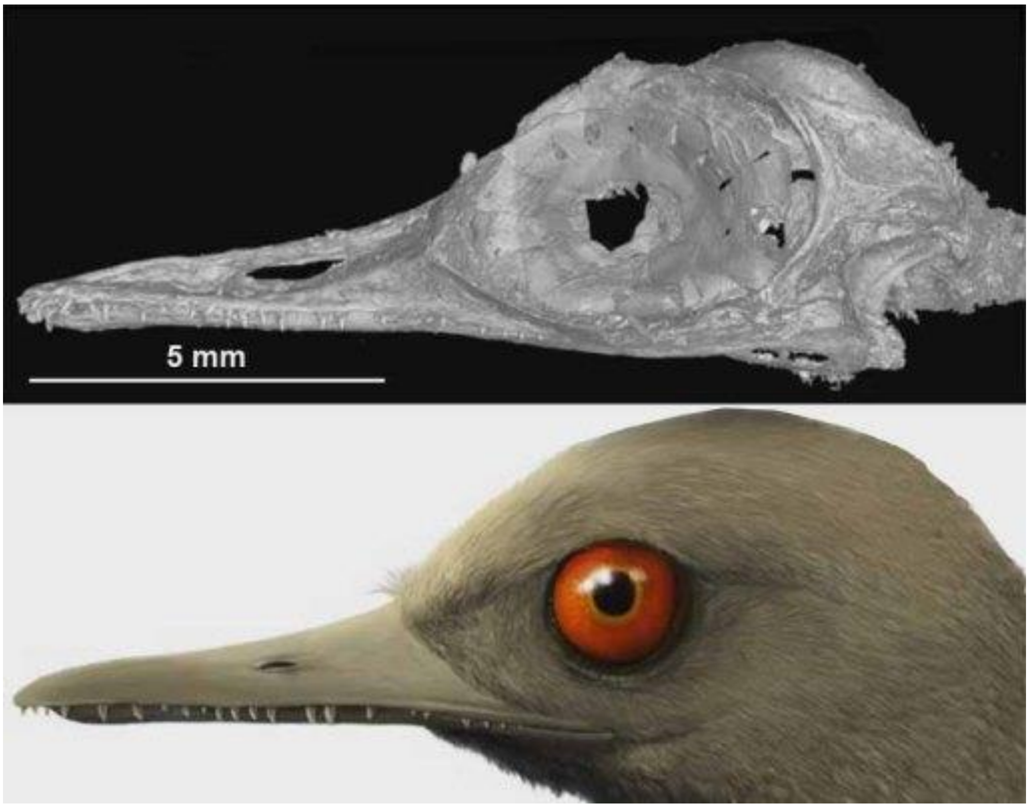
See also: Morris, A. 2020 Earth was stressed before dinosaur extinction (Northwestern University)

Dinosaur corner (March 2020)

Many adjectives have been applied to dinosaurs: terrifying; lumbering; long-dead; fierce; huge; nimble, carnivorous; herbivorous and so on. But exquisite and tiny do not immediately spring to mind. The mineral amber – strictly speaking a mineraloid because it isn't crystalline – having formed from resins exuded by trees, preserves materials, including animals, which became trapped in the resin. The shores of the Baltic Sea used to be the main source of this semi-precious gemstone, but it has been overtaken by high-quality supplies from Kachin State in Myanmar. Most specimens contain small invertebrates, including spiders and insects, in varying states of preservation. Once in a while truly spectacular amber pebbles turn up. In early March 2020 the world's media splashed a unique find: a miniature dinosaur (Xing, L. *et al*. 2020. Hummingbird-sized dinosaur from the Cretaceous period of Myanmar. *Nature* v. **579**, p. 245–249; DOI: 10.1038/s41586-020-2068-4).

Amber pebble from Myanmar containing a tiny vertebrate's skull (credit: Lida Xing, China University of Geosciences)

The amber specimen, from Middle Cretaceous (99 Ma) sediments, contains a perfectly preserved skull less than 2 cm long. At first glance it appears to be that of a tiny bird. The authors used micro-CT scanning to reconstruct the entire skull in 3-D. Although superficially resembling that of a bird, with eye sockets ringed by scleral ossicles that modern birds also have. These suggest that the animal was active during the daytime. Its beak-like jaws have many small teeth, as do many ancient fossil birds but not modern ones. These features led to its name: *Oculudentavis khaungraael,* translated as 'eye-tooth bird'. So, is it a bird? A number of features shown by the skull suggest that, strictly speaking, it is not. Anatomically, it is a dinosaur, possibly descended from earlier types, such as the Jurassic winged and feathered dinosaur *Archaeopterix,* which evolved to early, true birds with which *Oculudentavis* coexisted during the Cretaceous Period. Having teeth, it was probably carnivorous and preyed on invertebrates: it may have been fatally attracted to tree resin in which insects had been trapped.



Micro-CT image of Oculudentavis khaungraael skull (top); artist's impression of it in life (bottom) (credits: Xing, L. et al. 2020; Jingmai O'Connor, China University of Geosciences)

Even if it was a bird , it is smaller than the smallest living example, the bee hummingbird (*Mellisuga helenae*) and, weighing an estimated 2 grams, *Oculudentavis* is about one-sixth the size of the smallest known fossil bird. As a dinosaur, it is two orders of magnitude smaller than the most diminutive example of those found as fossils, the chicken-sized *Compsognathus*. Rather than being just an oddity, *Oculudentavis* demonstrates that extreme miniaturisation among avian dinosaurs held out evolutionary advantages.

Watch a video about the discovery and analysis of the tiny dinosaur

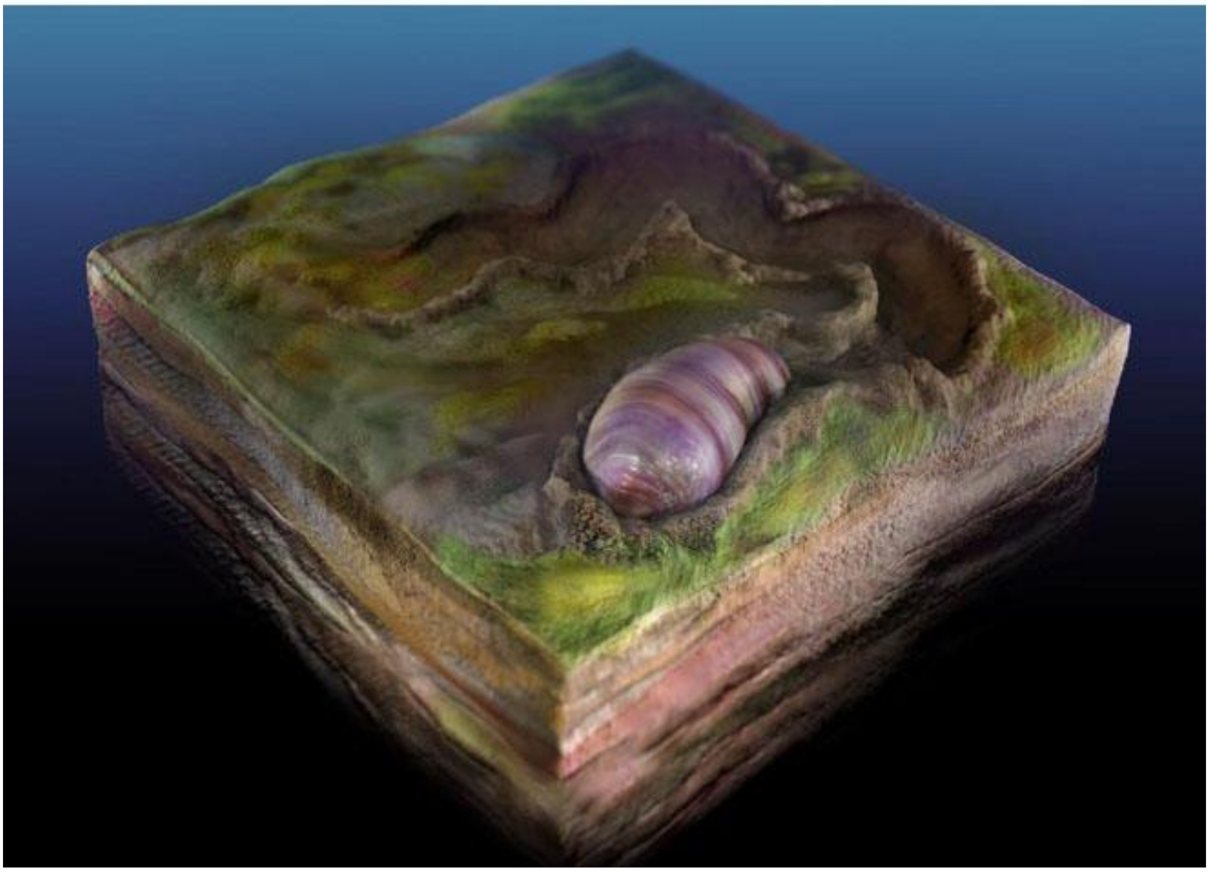
See also: Benson, R.B.J. 2020. Tiny bird fossil might be the world's smallest dinosaur. *Nature*, v. **579**, p. 199-200; DOI: 10.1038/d41586-020-00576-6.

Artist's rendering of a Middle Jurassic coastal plain in what is now the Isle of Skye across which a mixed dinosaur megafauna is migrating (credit: De Polo et al. 2020; Fig. 24; artist Jon Hoad)

And now for the lumbering and sometimes scary kinds of dinosaur. Since discovery of Middle Jurassic sauropod and theropod trackways with up to 0.5 m wide footprints at Brothers' Point on the Trotternish Peninsula of Skye, the Inner Hebridean island has become a magnet for those wishing to commune with big beasts. Now the same team from the University of Edinburgh report more from the same locality (De Polo, P.E. and 9 others 2020. Novel track morphotypes from new tracksites indicate increased Middle Jurassic dinosaur diversity on the Isle of Skye, Scotland. *PLoS ONE*, v. **15**, article e0229640; DOI: 10.1371/journal.pone.0229640). One set, referred to as *Deltapodus* was probably made by a species of stegosaur: the one with vertical plates on its back and a tail armed with large spikes, animated caricatures of which figure in inane YouTube clips, especially beating off Tyrannosaurs. The new locality preserves 50 dinosaur tracks that suggest a rich community of species. The most prominent suggest bipedal ornithopod herbivores and small, possible carnivorous theropods, both with three-toed feet, large quadripedal sauropods whose prints resemble those of elephants, as well as those with larger back feet than front attributed to stegosaurs. The sediment sequence displaying the tracks contains structures typical of deposition on a wide coastal plain.

A lowly worm from the Ediacaran? (March 2020)

Humans are more or less symmetrical, our left and right sides closely resembling each other. That is not quite so true for our innards, except for testes and ovaries, kidneys, lungs, arteries and veins, lymph and nervous systems. We have front- and rear ends, top and bottom, input and output orifices. All of that we share with almost all other animals from mammals to worms, particularly at the earliest, embryonic stage of development. We are bilaterians, whereas sponges, ctenophores, placozoans and cnidarians are not – having either no symmetry at all, or just a bottom and a top – and are in a minority. Fossil collections from Cambrian times also reveal bilaterians in the majority, at least insofar as preservation allows us to tell. Before 541 Ma ago, in the Precambrian, there are few signs of such symmetry and faunas are dominated by the flaccid, bag like creatures that form much of the Ediacaran Fauna, although there are traces of creatures that could move and graze, and had a rudimentary sense of direction (see: *Burrowers: knowing front from back*, July 2012 and *Something large moved 2 billion years ago; February 2019)*). Unsurprisingly, palaeobiologists would like to know when 'our lot' arose. One route is via comparative genetics among living animals, using DNA differences and the 'molecular clock' approach to estimate the age of evolutionary separation between 'us' and 'them'. But the spread of estimated ages is so broad as to render them almost meaningless. And the better constrained ages of very old trace fossils rely on accepting an assumption that they were, indeed, formed by bilaterians. Yet ingenuity may have revealed an actual early bilaterian from such traces.



*Top: Ediacaran burrow tracefossil (*Helminthoidichnites*) with suspected* burrower – arrow; bottom: reconstruction of *Ikaria wariootia*

Palaeobiologists from the US and Australia have scoured the famous Ediacara Hills of South Australia for traces of burrowing and signs of the animal that did it (Evans, S.D. *et al*. 2020. Discovery of the oldest bilaterian from the Ediacaran of South Australia. *Proceedings of the National Academy of Sciences*, v. **117**, online; DOI: [10.1073/pnas.2001045117](https://doi.org/10.1073/pnas.2001045117)). One Ediacaran trace fossil, known as *Helminthoidichnites* is preserved as horizontal trails on the tops and bottoms of thin, discontinuous sand bodies. Luckily, these are sometimes accompanied by elongate ovoids, like large grains of rice. From numerous laser scans of these suspected burrowers, and the traces that they left the authors have reconstructed them as stubby, possibly segmented, worm-like animals that they have called *Ikaria wariootia*, which may have grazed on algal mats. This name is derived from the local Adnyamathanha people's word (*Ikara* or 'meeting place') for the locality, a prominent landmark, near Warioota Creek. The age of the sedimentary sequence is between 551 to 560 Ma, and perhaps a little earlier. They *could* be the earliest-known bilaterians, but the sandy nature of the rocks in which they occur precludes preservation of the necessary detail to be absolutely sure: that would require silt- or. clay-sized granularity

See also: Fossil worm shows us our evolutionary beginnings (BBC, Science and Environment)

Early days of the dog (April 2020)

Wolves and dogs are interfertile and the mating of a domestic dog with a wolf results in fertile offspring, unlike the case with hybrids of horse and donkey, lion with tiger etc. This suggests that both canids are so closely related that domestication of wolves led to the entire range of dog breeds shown at Crufts every year. The question is, "When did humans first domesticate wolves"? Provided the instinctive 'rules' of wolves are followed by a human a wolf pup can become a pet, if it is taken from its mother between 14 and 21 days after birth. But, not only are they expensive to feed on raw meat, they may well attack a stranger as they would in the wild go for a wolf from another pack. They are often loyal and playful towards whoever raised them, but are strictly 'one-person' animals, and difficult to train because they easily become bored. Taming wolf puppies and deliberate selection is one route to domestication and the first dogs, another being 'self-domestication' when wolves become dependent on humans for a share in food.

Raven the wolf greets a visitor to the Mission: Wolf sanctuary in Colorado USA (credit: Wikipedia)

Comparison of wolf (*Canis lupus*) and domestic dog (*Canis familiaris*) genomes suggest an age of divergence for the two populations may have occurred between 20 to 60 thousand years ago. Indeed the DNA of wolf remains from Siberia showed it to belong to a wolf population whose descendants contributed to domestication of sledge dogs, such as Greenlandic huskies and Alaskan malemutes. Yet this approach is difficult and the results uncertain. Discovery of canid skulls associated with the remains of humans and mammoths at a 28.5 ka old site in the Czech Republic seems to have resolved both a minimum age for domestication and how it was achieved (Prassack, K.A. *et al*. 2020. Dental microwear as a behavioral proxy for distinguishing between canids at the Upper Paleolithic (Gravettian) site of Předmostí, Czech Republic. *Journal of Archaeological Science*, v. **115**, published online; DOI: 10.1016/j.jas.2020.105092).

A Palaeolithic canid skull from Předmostí, Czech Republic with the remains of a bone in its mouth which may have choked it, or which may have been placed there on burial

The Předmostí canids show two skull shapes: one with long jaws like wolves, the other with shorter, more dog-like jaws. Kari Prassack of the US National Park Service and colleagues from the USA, the Czech Republic and Belgium, turned to dental micro-wear patterns to resolve differences between the two groups as regards diet. Teeth from the more wolf-like group showed wear patterns consistent with a diet dominated by raw flesh, whereas the short-jawed canids ate mainly hard, brittle foods, probably bones. A truly remarkable find at the site was a near-complete canid skull of the short-jawed type, with a bone between its front teeth. Could this be a sign of a carefully buried pet 'proto-dog'?

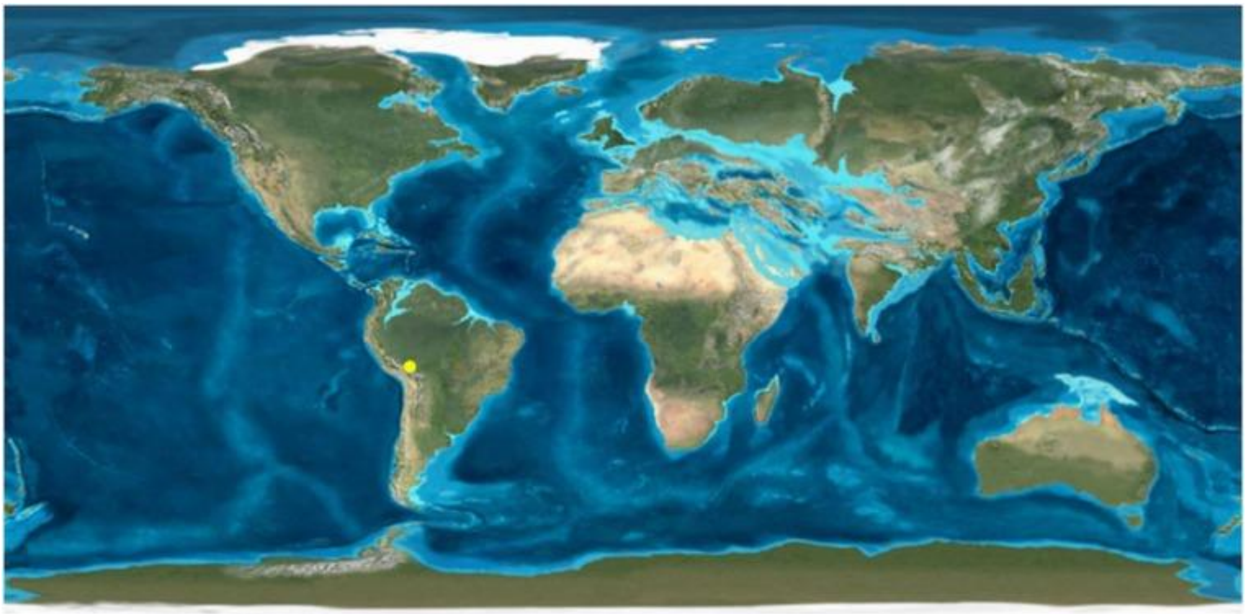
Earlier studies of the Předmostí canids included isotopic analyses of their bones, and those of associated humans. Interestingly, the more wolf-like group and the humans had diets dominated by mammoth flesh. The possible proto-dogs had focused on reindeer and other prey, as had the lions whose bones also occur at the site. This further complicates interpretation. Did both wolves and proto-dogs accompany the humans, the first being fed with mammoth meat that they helped bring down, while the second were fed scraps from smaller, more commonly killed prey? Perhaps the early dogs developed over a long period as scavengers on the kills of lions, and then became associates of humans. Yet neither canid would find a mammoth easy prey, even hunting in packs. So did the ice-age hunters have two companion animals, perhaps one to help in hunting mammoth, the other for more day-to-day hunting, which became more domesticated and even kept as pets? As the authors

conclude; more data are needed.

See also: Dog domestication during ice age (Science Daily)

How did monkeys get to South America? (April 2020)

This is one of the great mysteries of palaeontology. There are plenty of monkey species living today in South and Central America and in Mexico but none in North America. They are members of five families, collectively known as platyrrhine ('flat-nosed') primates, all having wide-spaced nostrils compared with the primates of the 'Old World'. They are the catarrhines ('hook-nosed). There are other differences, such as the unique prehensile tails of many 'New World' monkeys. The two monkey groups are genetically related, but their last common ancestor is estimated, using the 'molecular clock' approach, to have lived at least 31 Ma ago, in the Oligocene. The earliest platyrrhine primates of the Americas date to around the Eocene-Oligocene boundary (34 Ma). Interestingly, they are predated by the earliest rodent remains by only a few million years (41 Ma). Both primates and rodents had been inhabiting other continents long before this, so it is certain that, somehow, members of the two groups must have migrated to become isolated in the Americas. The problem lies with palaeogeography. By the late-Eocene the Americas were completely separated from Eurasia and Africa by the actively spreading Atlantic Ocean, then between 1500 to 2000 km wide. Complete isolation of the Americas dates from around 60 Ma ago, when the northernmost part of the North Atlantic began to open. The South Atlantic had become a wide ocean long before that, beginning in the far south during the early Cretaceous Period (138 Ma), with the mid-Atlantic Ridge steadily propagating northwards thereafter.



World palaeogeography at the Eocene-Oligocene boundary. The site of a recent fossil primate discovery in eastern Peru is marked by the yellow dot.

Since 60 Ma years ago it would have been impossible for the ancestors of 'New World' rodents and primates simply to have walked there. In any case the earliest known primate fossils from China are just 55 Ma old. Island hopping across the far northern, narrowest part of the North Atlantic during the Eocene may have been possible, although many islands there could have been subject to intense volcanic activity, as is Iceland today. The only alternative is a sea trip across the mighty Atlantic. Unless, that is, there is a hitherto undiscovered land bridge. The Walvis-Rio Grande Rise – a hotspot track – that spans the South Atlantic Ocean floor from Namibia to São Paulo in Brazil, has been the subject of some speculation since it is dotted with sea mounts and in places has micro-continental fragments. But it is too deep to have emerged as a result of falls in sea level. To suggest that the > 1500 km migration to the Americas of ancestral platyrrhine primates, or rodents for that matter, involved their being carried on drifting vegetation rafts obviously invites scepticism. For starters, why only two groups of animals? Or, could that imply a one-off event carrying only ancestral rodents and monkeys? It would need to be a special kind of raft: large enough to provide security against storm waves; immune to waterlogging, and carrying substantial food. On the plus side, there are powerful east-to-west currents in the equatorial Atlantic and trade winds going in the same direction, thanks to the Coriolis effect and ultimately Earth's rotation. Islands as 'way-points' or temporary refuges are less convincing, for they would have to be heavily vegetated themselves to provide onward rafts. Apparently, in the absence of anything more plausible, Sherlock Holmes's principle points to trans-Atlantic rafting.

This issue recently became 'live' again, with a fossil discovery in Peru, in an upper Amazon river bank close to at the Andean watershed but around 4000 km from the east coast of South America (Seiffert, E.R. *et al*. 2020. A parapithecid stem anthropoid of African origin in the Paleogene of South America. *Science*, v. **368**, p. 194-197; DOI: 10.1126/science.aba1135). The site had previously yielded both playrrhine monkey and rodent remains. To these have been added teeth with distinct similarities to those of fossils previously known only from Egypt, Libya and Tanzania: parapithecid anthropoids whose teeth are sufficiently different from those of platyrrhines to warrant a separate suborder, which includes baboons and primates. This is the only trace of parapithecids in South America and it may be assumed that, although they were possibly fellow-travellers with New World monkey ancestors, they were unable to compete and became extinct.

However, there is another possibility. Albeit with a sparse record of fossils resembling primates, North America does have at least one. George Gaylord Simpson (1902-1984), once the doyen of US palaeontologists, found a marmoset-like fossil in the early-Eocene of Wyoming, which he named *Teilhardinia* after the French Jesuit philosopher and palaeontologist Teihard de Chardin. It is about 56 Ma old and the size of a mouse. So was this diminutive creature the pioneer New World primate that crossed the northern North Atlantic? If so it would have had an equally perilous journey to reach South America, because the Isthmus of Panama was also open sea until around 4.5 Ma ago. With *Teilhardinia*, the plot thickens for there are several known species: in the US *T. brandti* from Wyoming and *T. magnoliana* from Mississippi; in Asia and Europe *T. asiatica* and *T. belgica* respectively. An embarrassment of riches that may well ignite: it has been suggested that North American *Teilhardinia* may have been the first of all primates and spread across the Eocene forests of North America, Europe and Asia. That hypothesis sort of implies that the entry of monkeys into South America may well have started with the tiny continent hopper who passed on its proclivities to its descendants in Africa

See also: Godinot, M. 2020. Rafting on a wide and wild ocean. *Science*, v. **368**, p. 136-137; DOI: 10.1126/science.abb4107; Ancient teeth from Peru hint now-extinct monkeys crossed Atlantic from Africa. *Science Daily*, 9 April 2020. Oldest-known ancestor of modern primates may have come from North America, not Asia. *Science Daily*, 29 November 2018

Pterodactyl corner (April 2020)

Published on April 23, 2020 Leave a comment

I recall an anecdote related by David Attenborough about a celebrity reception that he once attended one evening after he had been filming for a sequence on the aerodynamics of pterodactyls. A venerable and obviously well connected lady engaged him in conversation, and asked him what he had been doing recently. "Actually, today I was flying a pterodactyl". To which the old lady retorted, "Yes, they are *so* graceful, aren't they". They do have a large following, perhaps second only to dinosaurs, and three interesting items came to my attention in the last couple of weeks.

One of the known pterosaur groups is the Tapejaridae, comprising small to medium-sized pterosaurs with wingspans up to 4 m. They are quite spectacular in appearance, having large crests relative to their overall size. Their fossils have turned up in Cretaceous sediments in South America, Europe and China, and a new find in Morocco (*Afrotapejara zouhrii)* extends their range to Africa (Martill, D.M. *et al*. 2020. A new tapejarid (Pterosauria, Azhdarchoidea) from the mid-Cretaceous Kem Kem beds of Takmout, southern Morocco. *Cretaceous Research*. V. **112**: onlin, 104424; DOI: 10.1016/j.cretres.2020.104424). **See also:** De Lazaro, E. 2020. New species of pterosaur discovered in Morocco (*Sci News*, 6 April)

Also reported in *Cretaceous Research* are three new species of toothed, fish-eating pterosaurs of the ornithocheirid group. They too come from the Cretacous Kem Kem beds of Morocco, and again adding Africa to the range of the genera to which they belong. Even the largest flying animals known to science have emerged from the same strata. These are the azhdarchid pterosaurs, the largest of which had a wing span of more than 9 metres and stood at the height of a giraffe when on the ground.

See: Anderson, N, 2020**.** New pterosaur fossils unearthed in Morocco (*Sci News*, 26 March)

Being so widely spread, these pterosaur group's mode of flight must have been extremely efficient, perhaps even matching that of today's albatrosses, which use turbulence over ocean waves to glide effortlessly, indeed the epitome of graceful travel. How they achieved such vast ranges is partly due to their extremely light-weight bones that were paper thin but strong because they contained vesicles filled with gas, much like the expanded polystyrene used in model pterosaurs of the kind flown by 'Whispering Dave' as Sir David Attenborough is fondly known. Their bone structures are similar, in this respect, to those of modern birds.

Reconstruction of the giant pterosaur Hatzegopteryx *launching into the air, just after the forelimbs have left the ground (credit: Mark Witton)*

So, how did these graceful beasts fly? Like those of bats, pterosaurs' wings were membranes, but rather than being supported by five elongated digits, as in bats, those of pterosaurs extended from their bodies to a single elongated 'finger' or digit: hence their old name pterodactyl, translated from the Greek as 'wing finger'. For a long while, it was believed that pterosaurs had to live on high ground, even cliffs, in order to launch themselves in the manner of a hang glider. Reconstructions of their gait on the ground generally look extremely ungainly: they walked on their 'wrists' and the other three, small 'fingers' of their forelimbs.. How they probably launched themselves emerges from a detailed paper linking natural flight modes of birds, bats and pterosaurs to conceivable developments in aeronautics inspired by them (Martin-Silverstone, E. *et al*. 2020. Volant fossil vertebrates: potential for bioinspired flight technology. *Trends in Ecology and Evolution*, v. **35**, in press 9 April 2020; DOI: 10.1016/j.tree.2020.03.005). The authors point to the great strength of the membrane structure itself, conferred by its three-layered structure, and to the aerodynamic properties of the wing. They conclude that, whereas pterosaurs were probably incapable of high-speed flight, they were extremely efficient at low speeds, ideal for soaring and for low-speed landing that would not endanger their fragile bodies. Simply by springing into the air using all four limbs they could attain sustained flight, although the largest of them were close to the limit. The necessary muscles actually made up about 40% of their body mass. See a reconstruction of the launch of the largest pterosaur, *Quetzalcoatlus* from the Late Cretaceous of North America

See also: Fossil Flyers Hold Secrets to Better Flight Technologies (*Sci News*, 18 April)

Genetic material from a baby dinosaur (May 2020)

Recently, a lot of publicity focussed on stunning CT scans of embryos preserved in fossilised eggs of a Jurassic sauropodomorph dinosaur, which were obtained using very high energy X-rays generated by a synchrotron in France (Chapelle, K.E.J. *et al.* 2020. Conserved in-ovo cranial ossification sequences of extant saurians allow estimation of embryonic dinosaur developmental stages. *Nature Scientific Reports*, v. **10**, article 4224; doi: 10.1038/s41598-020-60292-z). The images suggest that the embryos' skulls developed in much the same way as do those of living reptiles. Within a week there emerged an even more compelling dinosaurian scoop: a fossil nestling of a duck-billed dinosaur (hadrosaur) from the Upper Cretaceous of Montana is reported to have yielded evidence for a broad spectrum of cellular materials (Bailleul, A.M. *et al*. 2020. Evidence of proteins, chromosomes and chemical markers of DNA in exceptionally preserved dinosaur cartilage. *National Science Review*, v. 7, advance publication NWZ206; DOI: 10.1093/nsr/nwz206).

A clutch of Massospondylus carinatus *eggs from the Jurassic of South Africa (credit: Brett Eloff)*

Alida Bailleul, who works at the Chinese Academy of Sciences in Beijing, and fellow molecular palaeontologists from Canada, the US and Sweden, examined material from the nestling's skull that was suspected to contain traces of cartilage. Their methods involved microscopic studies of thin sections together with staining and fluorochemical analysis of cellular material extracted by dissolving away bone tissue in acid. The same methodologies were also applied to similar material from modern emu chicks as a means of validating the results from the fossil. Staining used the same chemical that previously had revealed blood proteins in a specimen of *Tyrannosaurus rex* (see: *Blood of the dinosaurs* in Palaeobiology, January 2011). The fluorescence approach dosed the dinosaur cartilage with antibodies against bird collagen, and revealed an immune reaction (green fluorescence) in both fossil material and that from the baby emus.

The researchers also isolated cartilage cells (chondrocytes) from the dinosaur preparations. Two stains (PI and DAPI, for short) that show up DNA were applied, giving positive responses. The PI (propidium iodide) stain is useful as it does not respond to DNA in living material, bit only to that in dead cells, thereby helping to rule out contamination with modern material. Apparently, the double-staining experiments support the presence of double-stranded material that involves at least six base pairs (of ACTG amino acids). This does not prove the existence of dinosaur DNA, but does demonstrate that the hadrosaur's cell nuclei are preserved.

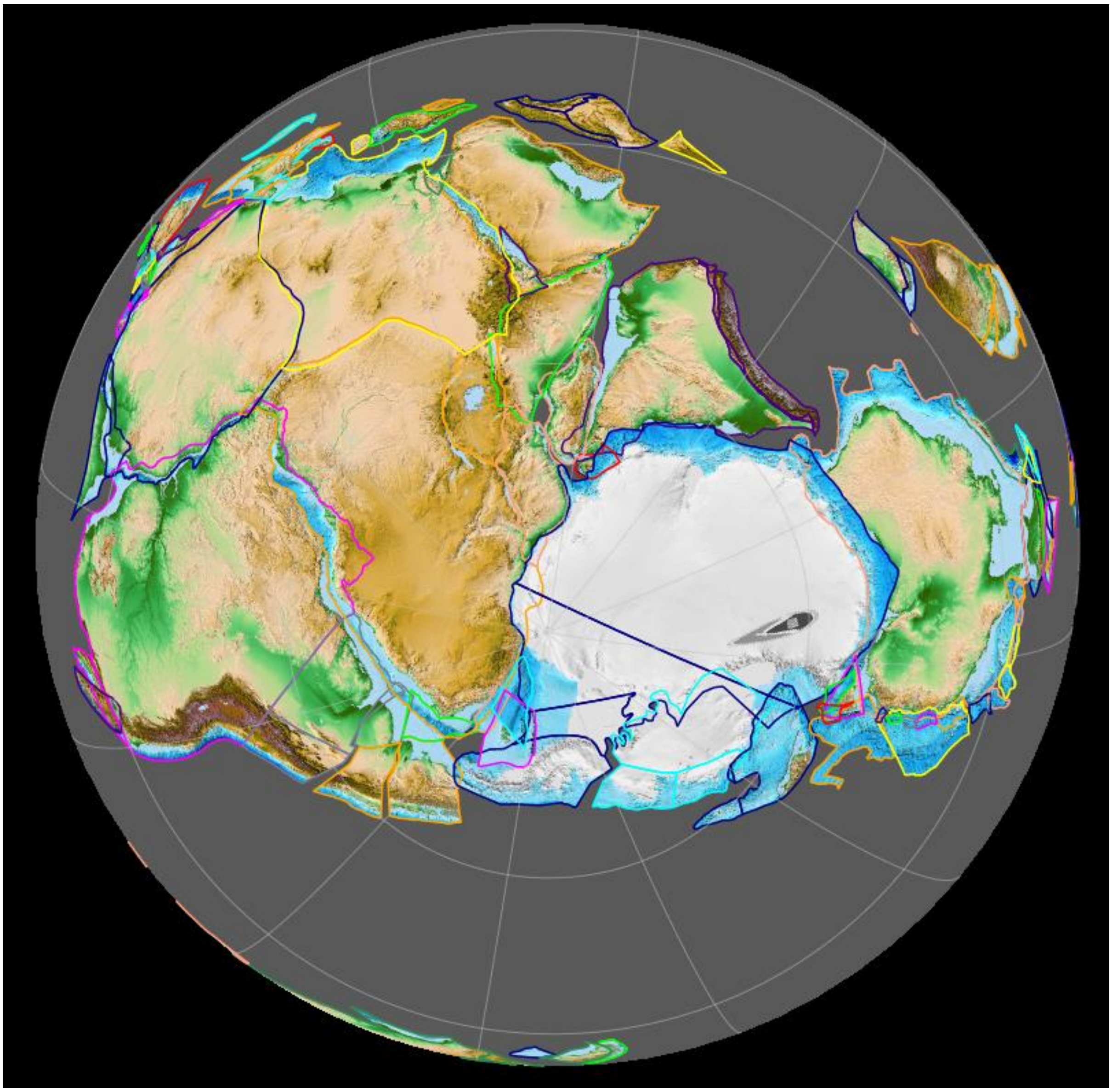
Does that suggest that the hunt is on for a dinosaur genome, with all its connotations? OK, a complete genome has been extracted from a frozen Siberian mammoth a few tens of thousand years old, which encourages 're-wilding' aficionados, but that animal preserved intact cells of many kinds. A 70 Ma old dinosaur fossil, however exquisitely preserved, is mostly 'rock', in that preservation is through mineralisation of bone and tissue, and even cells … Moreover, it is possible that what the team found may even be material from post-mortem bacterial colonisation of any age younger than 70 Ma.

See also: De Lazaro, E. 2020. Scientists Use X-rays to Peer inside Fossilized Dinosaur Eggs *Sci News*, 10 April 2020; Black, R. 2020. Possible dinosaur DNA has been found. *Scientific American*, 17 April 2020

Geochemistry and the Ediacaran animals (June 2020)

Hopefully, readers will be fairly familiar with the sudden appearance of the Ediacaran fauna – the earliest abundant, large animals – at the start of the eponymous Period of the Neoproterozoic around 635 Ma. If not, use the Search Earth-logs box in the side bar to find extensive coverage since the start of the 21st century. A June 2019 Earth-logs review of the general geochemical background to the Ediacaran Period can be found here. Ten years ago I covered the possible role of the element phosphorus (P) – the main topic here – in the appearance of metazoans (see: Phosphorus, Snowball Earth and origin of metazoans – November 2010).

One of the major changes in marine sedimentation seen during the Ediacaran was a rapid increase in the deposition on the ocean floor of large bodies of P-rich rock (phosphorite), on which a recent paper focuses (Laakso, T.A. *et al*. 2020. Ediacaran reorganization of the marine phosphorus cycle. *Proceedings of the National Academy of Sciences, v.* ***117****, p. 11961-11967; DOI:* 10.1073/pnas.1916738117). It has been estimated that on million-year time scales phosphorites remove only a tiny amount of the phosphorus carried into the oceans by rivers. So, conversely, an increase in deposition of marine P-rich sediment would have little effect on the overall availability of this essential nutrient from the oceans. The Ediacaran boost in phosphorites suggests a connection between them and the arrival of totally new ecosystems: the global P-cycle must somehow have changed. This isn't the only change in Neoproterozoic biogeochemistry. Thomas Laakso and colleagues note signs of slightly increased ocean oxygenation from changes in sediment trace-element concentrations, a major increase in shallow-water evaporites dominated by calcium sulfate (gypsum) and changes in the relative proportions of different isotopes of sulfur.



The Gondwana supercontinent that accumulated during the Neoproterozoic to dominate the Earth at the time of the Ediacaran (credit: Fama Clamosa, at Wikimedia Commons)

Because all marine cycles, both geochemical and those involving life, are interwoven, the authors suggest that changes in the fate of dead organic matter may have created the phosphorus paradox. Phosphorus is the fifth most abundant element in all organisms after carbon, hydrogen, nitrogen and oxygen, followed by sulfur (CHNOPS), P being a major nutrient that limits the sheer bulk of marine life. Perhaps changes to dead organic matter beneath the ocean floor released its phosphorus content, roughly in the manner that composting garden waste releases nutrients back to the soil. Two chemical mechanisms can do this in the deep ocean: a greater supply of sinking organic matter – essentially electron donors – and of oxidants that are electron acceptors. In ocean-floor sediments organic matter can be altered to release phosphorus bonded in organic molecules into pore water and then to the body of the oceans to rise in upwellings to the near surface where photosynthesis operates to create the base of the ecological food chain.

There is little sign of much increase in deep-ocean oxygen until hundreds of million years after the Ediacaran. It is likely, therefore, that increased availability of oxidant sulfate ions (SO_4^{2-}) in ocean water and their reduction to sulfides in deep sediment chemically reconstituted the accumulating dead organic matter to release P far more rapidly than before. This is supported by the increase in $CaSO_4$ evaporites in the Ediacaran shallows. So, where did the sulfate come from? Compressional tectonics during the Neoproterozoic Era were at a maximum, particularly in Africa, South America, Australia and Antarctica, as drifting continental fragments derived from the break-up of the earlier Rodinia supercontinent began to collide. This culminated during the Ediacaran around 550 Ma ago with assembly of the Gondwana supercontinent. Huge tracts of it were new mountain belts whose rapid erosion and chemical weathering would have released plenty of sulfate from the breakdown of common sulfide minerals.

So the biological revolution and a more productive biosphere that are reflected in the Ediacaran fauna ultimately may have stemmed from inorganic tectonic changes on a global scale

Fossil fuel, mercury and the end-Palaeozoic catastrophe June 2020)

Siberian flood-basalt flows in the Putorana Plateau, Taymyr Peninsula, Russia. (Credit: Paul Wignall)

The end of the Permian Period (~252 Ma ago) saw the loss of 90% of marine fossil species and 70% of those known from terrestrial sediments: the greatest known extinction in Earth's history. In their naming of newly discovered life forms, palaeontologists can become quite lyrical. Extinctions, however, really stretch their imagination. They call the Permo-Triassic boundary event 'The Great Dying'. Why not 'Permageddon'? Sadly, that was snaffled in the 1980s by an astonishingly short-haired heavy-metal tribute band. Enough bathos … The close of the Palaeozoic left a great many ecological niches to be filled by adaptive radiation during the Triassic and later Mesozoic times. Coinciding with the largest known flood-basalt outpouring – the three million cubic kilometres of Siberian Traps – the P-Tr event seemed to be 'done and dusted' after that possible connection was discovered in the mid 1990s. Notwithstanding, the quest for a gigantic, causative impact crater continues (see: Palaeobiology Earth-logs, May, September and October 2004), albeit among a dwindling circle of enthusiasts. The Siberian Traps are suitably vast to snuff the fossil record, for their eruption must have belched all manner of climate-changing gases and dusts into the atmosphere; CO_2 to encourage global warming; SO_2 and dusts as cooling agents. There is also evidence of a role for geochemical toxicity (see: Nickel, life and the end-Permian extinction, June 2014). The extinctions accompanied not only climate change but also a catastrophic fall in atmospheric oxygen content (see: Homing in on the great end-Permian extinction, April 2003; When rain kick-started evolution, December 2019). Recovery of the biosphere during the early Triassic was exceedingly slow.

Research focussed on the P-Tr boundary eventually uncovered an element of pure chance. Shales in Canada that span the boundary show major, negative $\delta^{13}C$ excursions in the carbon-isotope record that coincide with fly ash in the analysed layers. This material is similar in all respects to that emitted from coal-fired power stations (see: Coal and the end-Permian mass extinction, March 2011). The part of Siberia onto which the flood basalts were erupted is rich in Permian coal measures and oil shales that lay close to the surface 252 Ma ago. The coal ash and massive emissions of CO2 may have resulted from their burning by the flood basalt event. Now evidence has emerged that this did indeed happen (Elkins-Tanton, L.T. *et al*. 2020. Field evidence for coal combustion links the 252 Ma Siberian Traps with global carbon disruption. *Geology*, v. **48**, early publication; DOI: 10.1130/G47365.1).

The US, Canadian and Russian team found large quantities of burnt coal and woody material, and bituminous blobs in 600 m thick volcanic ashes at the base of the Siberian traps themselves. They concluded that the magma chamber from which the flood basalts emerged had incorporated sizeable volumes of the coal measures, leading to their combustion and distillation. This would have released CO_2 enriched in light ^{12}C due to isotopic fractionation by biological means, i.e. its $\delta^{13}C$ would have been sufficiently negative to affect the carbon locked up in the Canadian P-Tr boundary-layer shales that show the sharp isotopic anomalies. The magnitude of the anomalies suggest that between six to ten thousand billion tons of carbon released as CO_2 or methane by interaction of the Siberian Traps with sediments through which their magma passed could have created the global $\delta^{13}C$ anomalies. That is about one tenth of the organic carbon originally locked in the Permian coal measures beneath the flood basalts

Another paper whose publication coincided with that by Elkins-Tanton *et al*. suggests that environmental mercury appears to have followed the same geochemical course as did carbon at the end of the Palaeozoic Era (Dal Corso, J. and 9 others 2020. Permo–Triassic boundary carbon and mercury cycling linked to terrestrial ecosystem collapse. *Nature Communications*, v. **11**, paper 2962; DOI: 10.1038/s41467-020-16725-4). This group, based at Leeds and Oxford Universities, UK and the University of Geosciences in Wuhan, China, base their findings on biogeochemical modelling of the global carbon and mercury cycles at the end of the Permian. Their view is that the coincidence in marine sediments at the P-Tr boundary of a short-lived spike in mercury and an anomaly in its isotopic composition with the depletion in ^{13}C, described earlier, shows an intimate link between mercury and the biological carbon cycle in the oceans at the time. They suggest that this synergy marks ecosystem collapse and derives 'from a massive oxidation of terrestrial biomass'; i.e. burning of organic material on the land surface. Their modelling hints at huge wildfires in equatorial peatlands but also a role for the Siberian flood-basalt volcanism and the incorporation of coal measures into the Siberian Trap magma chamber.

Can a supernova affect the Earth System? (August 2020)

The easy answer is yes, simply because chemical elements with a greater relative atomic mass than that of iron are thought to be created in supernovae when dying giant stars collapse under their own gravity and then explode. Interstellar dust and gas clouds accumulate their debris. If the clouds are sufficiently dense gravity forms clumps that may become new stars and the planets that surround them. Matter from every once-nearby supernova enters these clouds and thus contributes to the formation of a planet. This was partly proven when pre-solar grains were found in the Murchison meteorite, some of which are as old as 7.5 billion years (Ga) – 3 Ga older than the Solar System (see: Mineral grains far older than the Solar System; January 15, 2020). Murchison is a carbonaceous chondrite, a class of meteorite which likely contributed lots of carbon-based compounds to the early Earth, setting the stage for the emergence of life. It has been estimated that a near-Earth supernova (closer than 1000 light years) would have noticeable effects on the biosphere, mainly because of the effects on atmospheric composition of the associated high-energy gamma-ray burst. That would create sufficient nitrogen oxides to destroy the ozone layer that shields the surface from harmful radiation. There are reckoned to have been 20 nearby supernovae during the last 10 Ma or so from the presence of anomalously high levels of the isotope ^{60}Fe in marine sediment layers on the Pacific floor. Yet there is no convincing evidence that they coincided with detectable extinctions in the fossil record. But supernovae have been suggested as a possible cause of more-ancient mass extinctions, such as that at the end of the Ordovician Period (but see: The late-Ordovician mass extinction: volcanic connections; July 2017).

Diorama of an Early Devonian reef system with crinoids, an ammonoid, tabulate and rugose corals and trilobites (Credit: Richard Bizley)

The Late Devonian is generally accepted to be one of the 'Big Five' mass extinction events. However, unlike the others, the event was a protracted decline in biodiversity, with several extinction peaks). In particular it marked the end of Palaeozoic reef-building corals. Some have put down the episodic faunal decline to the effects of species moving from one marine basin to another as global sea levels fluctuated: much like the effects of the 'invasion' of the coral-eating Crown of Thorns sea urchin that has helped devastate parts of the Great Barrier Reef during present-day global warming (see: Late Devonian: mass extinction or mass invasion? January 2012). Recently, attention has switched to evidence for ultra-violet damage to the morphology of spores found in the strata that display faunal extinction; i.e. to the possibility of the ozone layer having been lost or severely depleted. One suggestion has been sudden peaks in volcanic activity, hinted at by spikes in the abundance of mercury of marine sediments. Brian Fields of the University of Illinois, with colleagues from the USA, UK, Estonia and Switzerland, have closely examined the possibility and the testability of a supernova's influence (Fields. B.D. *et al*. 2020. Supernova triggers for end-Devonian extinctions. *Proceedings of the National Academy of Sciences*, v. **117**, article 202013774; DOI: 10.1073/pnas.2013774117).

They propose the deployment of mass-spectrometric analysis for anomalous stable-isotope abundances in the sediments that contain faunal evidence for accelerated extinction, particularly those of ^{146}Sm, ^{235}U and the long-lived plutonium isotope ^{244}Pu (80 Ma hal-life). They suggest that the separation of the extinction into several events, may be a clue to a supernova culprit. A gamma-ray burst would arrive at light speed, but dust – containing the detectable isotopes – although likely to be travelling very quickly would arrive hundred to thousands of years later, depending on the distance to the supernova. Cosmic rays generated by the supernova, also a possible kill mechanism, given a severely depleted ozone layer, travel about half the speed of light. Three separate arrivals for the products of a single stellar explosion are indeed handy as an explanation for the Late Devonian extinctions. But someone needs to do the analyses. The long-lived plutonium isotope is the best candidate: even detection of a few atoms in a sample would be sufficient proof. But that would require a means of ruling out contamination by anthropogenic plutonium, such as analysing the interior of fossils. But would even such an exotic discovery prove the sole influence of a galactic even?

Influence of massive igneous intrusions on end-Triassic mass extinction (September 2020)

About 200 Ma ago, the break-up of the Pangaea supercontinent was imminent. The signs of impending events are spread through the eastern seaboard of North America, West Africa and central and northern South America. Today, they take the form of isolated patches of continental flood basalts, dyke swarms – probably the feeders for much more extensive flood volcanism – and large intrusive sills. Break-up began with the separation of North America from Africa and the start of sea-floor spreading that began to form the Central Atlantic Ocean: hence the name Central Atlantic Magmatic Province (CAMP) for the igneous activity. It all kicked off at the time of the Triassic-Jurassic stratigraphic boundary, and a mass extinction with a similar magnitude to that at the end of the Cretaceous. Disappearances of animals in the oceans and on continents were selective rather than general, as were extinctions of land plants. The mass extinction is estimated to have taken about ten thousand years. It left a great variety of ecological niches ready for re-occupation. On land a small group of reptiles with a substantial destiny entered some of these vacant niches. They evolved explosively to the plethora of later dinosaurs as their descendants became separated as a result of continental drift and adaptive radiation.

Flood basalts of the Central Atlantic Magmatic Province in Morocco (Credit: Andrea Marzoli)

The end-Triassic mass extinction, like three others of the Big Five, was thus closely associated in time with massive continental flood volcanism: indeed one of the largest such events. Within at most 10 ka large theropod dinosaurs entered the early Jurassic scene of eastern North America. The Jurassic was a greenhouse world whose atmosphere had about five times more CO_2, a mean global surface temperature between 5 and 10°C higher and deep ocean temperatures 8°C above those at present. Was mantle carbon transported by CAMP magmas the main source (widely assumed until recently) or, as during the end-Permian mass extinction, was buried organic carbon responsible? A multinational group of geoscientists have closely examined samples from a one million cubic kilometre stack of intrusive basaltic sills, dated at 201 Ma, in the Amazon basin of Brazil that amount to about a third of all CAMP magmatism (Capriolo, M. and 11 others 2021. Massive methane fluxing from magma–sediment interaction in the end-Triassic Central Atlantic Magmatic Province. *Nature Communications*, v. **12**, article 5534; DOI: 10.1038/s41467-021-25510-w).

The team focussed on fluid inclusions in quartz within the basaltic sills that formed during the late stages of their crystallisation. The tiny inclusions contain methane gas and tiny crystals of halite (NaCl) as well as liquid water. Such was the bulk composition of the intrusive magma that the presence of around 5% of quartz in the basalts would be impossible without their magma having assimilated large volumes of silica-rich sedimentary rocks such as shales. The host rocks for the huge slab of igneous sills are sediments of Palaeozoic age: a ready source for contamination by both organic carbon and salt. The presence of methane in the inclusions suggests that more complex hydrocarbons had been 'cracked' by thermal metamorphism. Moreover, it is highly unlikely to have been derived from the mantle, partly because methane has been experimentally shown not to be soluble in basaltic magmas whereas CO_2 is. The authors conclude that both quartz and methane entered the sills in hydrothermal fluids generated in adjacent sediments. Thermal metamorphism of the sediments would also have driven such fluids to the surface to inject methane directly to the atmosphere. Methane is 25 times as potent as carbon dioxide at trapping heat in the atmosphere, yet it combines with the hydroxyl (OH^-) radical to form CO_2 and water vapour within about 12 years. Nevertheless during continuous emission methane traps 84 times more heat in the atmosphere than would an equivalent mass of carbon dioxide.

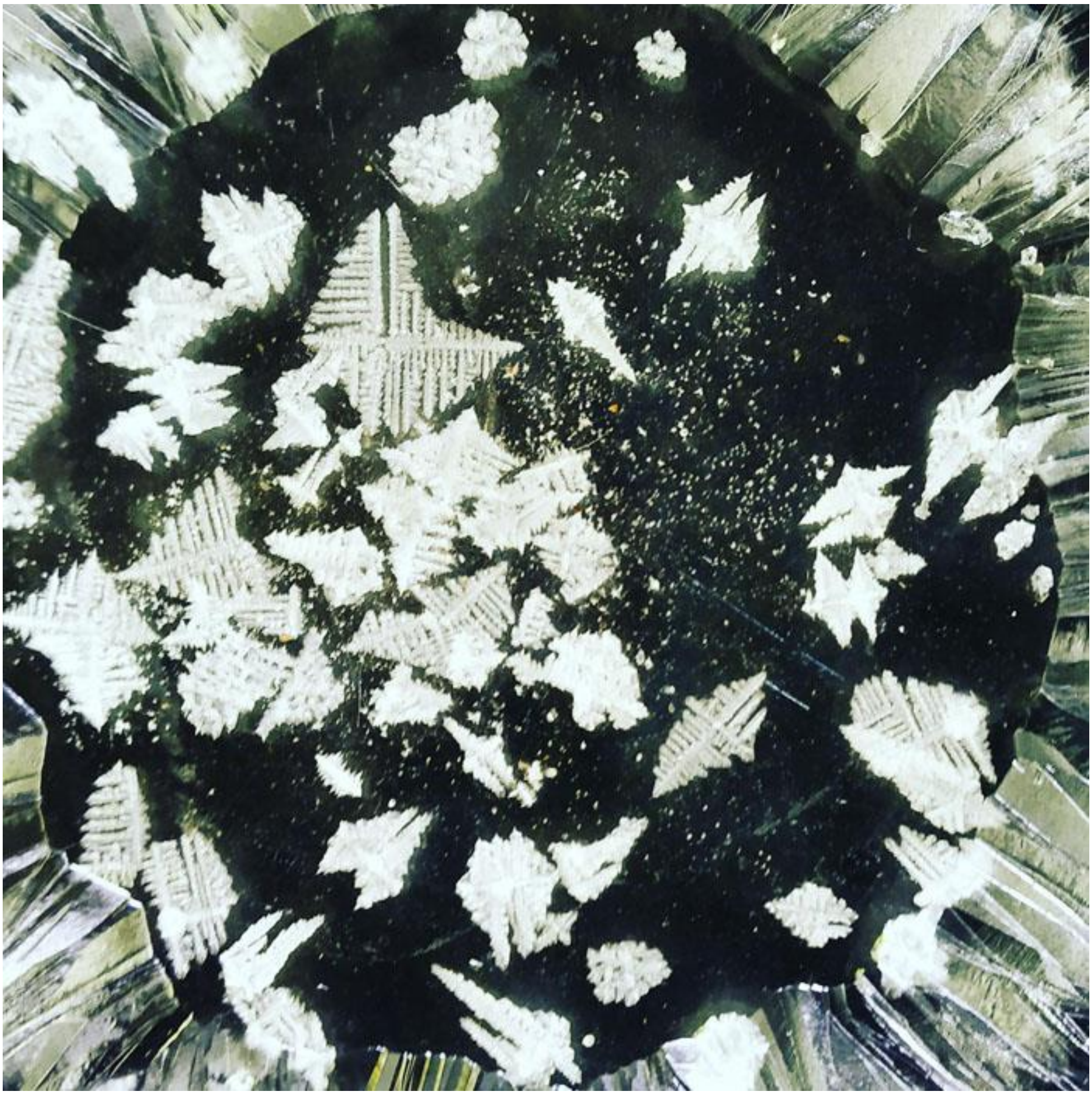
Calculations suggest about seven trillion tonnes of methane were generated by the CAMP intrusions in Brazil. Had the magmas mainly been extruded as flood basalts then perhaps global warming at the close of the Triassic would have been far less. Extinctions and subsequent biological evolution would have taken very different paths; dinosaurs may not have exploded onto the terrestrial scene so dramatically during the remaining 185 Ma of the Mesozoic. So it seems important to attempt an explanation of why CAMP magmas in Brazil did not rise to the surface but stayed buried as such stupendous igneous intrusions. Work on smaller intrusive sills suggests that magmas that are denser than the rocks that they pass through – as in a large, thick sedimentary basin – are forced by gravity to take a lateral 'line of least resistance' to intrude along sedimentary bedding. That would be aided by the enormous pressure of steam boiled from wet sedimentary rocks forcing beds apart. In areas where only thin sedimentary cover rests on crystalline, more dense igneous and metamorphic rocks, basaltic magma has a greater likelihood of rising through vertical dyke swarms to reach the surface and form lava floods.

Origin of life: some news (December 2020)

For self-replicating cells to form there are two essential precursors: water and simple compounds based on the elements carbon, hydrogen, oxygen and nitrogen (CHON). Hydrogen is not a problem, being by far the most abundant element in the universe. Carbon, oxygen and nitrogen form in the cores of stars through nuclear fusion of hydrogen and helium. These elemental building blocks need to be delivered through supernova explosions, ultimately to where water can exist in liquid form to undergo reactions that culminate in living cells. That is only possible on solid bodies that lie at just the right distance from a star to support average surface temperatures that are between the freezing and boiling points of water. Most important is that such a planet in the 'Goldilocks Zone' has sufficient mass for its gravity to retain water. Surface water evaporates to some extent to contribute vapour to the atmosphere. Exposed to ultraviolet radiation H_2O vapour dissociates into molecular hydrogen and water, which can be lost to space if a planet's escape velocity is less than the thermal vibration of such gas molecules. Such photo-dissociation and diffusion into outer space may have caused Mars to lose more hydrogen in this way than oxygen, to leave its surface dry but rich in reddish iron oxides.

Despite liquid water being essential for the origin of planetary life it is a mixed blessing for key molecules that support biology. This 'water paradox' stems from water molecules attacking and breaking the chemical connections that string together the complex chains of proteins and nucleic acids (RNA and DNA). Living cells resolve the paradox by limiting the circulation of liquid water within them by being largely filled with a gel that holds the key molecules together, rather than being bags of water as has been commonly imagined. That notion stemmed from the idea of a 'primordial soup', popularised by Darwin and his early followers, which is now preserved in cells' cytoplasm. That is now known to be wrong and, in any case, the chemistry simply would not work, either in a 'warm, little pond' or close to a deep sea hydrothermal vent, because the molecular chains would be broken as soon as they formed. Modern evolutionary biochemists suggest that much of the chemistry leading to living cells must have taken place in environments that were sometimes dry and sometimes wet; ephemeral puddles on land. Science journalist Michael Marshall has just published an easily read, open-source essay on this vexing yet vital issue in *Nature* (Marshall, M. 2020. The Water Paradox and the Origins of Life. *Nature*, v. **588**, p. 210-213; DOI: 10.1038/d41586-020-03461-4). If you are interested, click on the link to read Marshall's account of current origins-of-life research into the role of endlessly repeated wet-dry cycles on the early Earth's surface. Fascinating reading as the experiments take the matter far beyond the spontaneous formation of the amino acid glycine found by Stanley Miller when he passed sparks through methane, ammonia and hydrogen in his famous 1953 experiment at the University of Chicago. Marshall was spurred to write in advance of NASA's Perseverance Mission landing on Mars in February 2021. The Perseverance rover aims to test the new hypotheses in a series of lake sediments that appear to have been deposited by wet-dry cycles in a small Martian impact crater (Jezero Crater) early in the planet's history when surface water was present.

That CHON and simple compounds made from them are aplenty in interstellar gas and dust clouds has been known since the development of means of analysing the light spectra from them. The organic chemistry of carbonaceous meteorites is also well known; they even smell of hydrocarbons. Accretion of these primitive materials during planet formation is fine as far as providing feedstock for life-forming processes on physically suitable planets. But how did CHON get from giant molecular clouds into such planetesimals. An odd-sounding organic compound – hexamethylenetetramine ($(CH_2)_6N_4$), or HMT – formed industrially by combining formaldehyde (CH_2O) and ammonia (NH_3) – was initially synthesised in the late 19th century as an antiseptic to tackle UTIs and is now used as a solid fuel for lightweight camping stoves, as well as much else besides. HMT has a potentially interesting role to play in the origin of life. Experiments aimed at investigating what happens when starlight and thermal radiation pervade interstellar gas clouds to interact with simple CHON molecules, such as ammonia, formaldehyde, methanol and water, yielded up to 60% by mass of HMT.



Crystals of hexamethylenetetramine (Credit: r/chemistry, Reddit)

The structure of HMT is a sort of cage, so that crystals form large fluffy aggregates, instead of the gases from which it can be formed in deep space. Together with interstellar silicate dusts, such sail-like structures could accrete into planetesimals in nebular star nurseries under the influence of gravity and light pressure. Geochemists from several Japanese institutions and NASA have, for the first time, found HMT in three carbonaceous chondrites, albeit at very low concentrations – parts per billion (Y. Oba *et al.* 2020. Extraterrestrial hexamethylenetetramine in meteorites — a precursor of prebiotic chemistry in the inner Solar System. *Nature Communications*, v. **11**, article 6243; DOI: 10.1038/s41467-020-20038-x). Once concentrated in planetesimals – the parents of meteorites when they are smashed by collisions – HMT can perform the useful chemical 'trick' of breaking down once again to very simple CHON compounds when warmed. At close quarters such organic precursors can engage in polymerising reactions whose end products could be the far more complex sugars and amino acid chains that are the characteristic CHON compounds of carbonaceous chondrites. Yasuhiro Oba and colleagues may have found the missing link between interstellar space, planet formation and the synthesis of life through the mechanisms that resolve the 'water paradox' outlined by Michael Marshall.

See also: Scientists Find Precursor of Prebiotic Chemistry in Three Meteorites (*Sci-news*, 8 December 2020.)