Palaeontology, palaeobiology and evolution

Hadean potentially fertile for life (*February 2018)*

The earliest incontrovertible signs of life on Earth are in the 3.48 billion-year-old Dresser Formation in the Pilbara craton of Western Australia, which take the form of carbon-coated, bubble-like structures in fine-grained silica sediments ascribed to a terrestrial hot-spring environment. In the same Formation are stromatolites that are knobbly, finely banded structures made of carbonates. By analogy with similar structures being produced today by bacterial mats in a variety of chemically stressed environments that are inhospitable for multicelled organisms that might know them away, stromatolites are taken to signify thriving, carbonate secreting bacteria. There are also streaks of carbon associated with wave ripples that may have been other types of biofilm. A less certain record of the presence of life are stromatolite-like features in metasediments from the Isua supracrustal belt of West Greenland, dated at around 3.8 Ga, which also contain graphite with carbon-isotopic signs that it formed from biogenic carbon. Purely geochemical evidence that carbonaceous compounds may have formed in living systems are ambiguous since quite complex hydrocarbons can be synthesised abiogenically by Fischer-Tropsch reactions between carbon monoxide and hydrogen.

Metamorphosed volcanosedimentary rocks from the Nuvvuagittuq supracrustal belt, Canada. Some of these rocks contain possible evidence of fossil cells. (Credit: Wikipedia)

At present there is little chance of extending life's record further back in time than four billion years because the Hadean is mainly represented by pre 4 Ga ages of zircon grains found in much younger sedimentary rocks – resistant relics of Hadean crustal erosion. The eastern shore of Hudson Bay does preserve a tiny (20 km^2) patch of metamorphosed basaltic igneous rocks, known as the Nuvvuagittuq Greenstone Belt. Dated at 3.77 Ga by one method but 4.28 Ga by another, this *could* be Hadean. Like the Isua sequence that in Quebec also contains metasediments, including banded ironstones with associated iron-rich hydrothermal deposits. Silica from the vent system shows dramatically lifelike tubules. Yet the ambiguity in dating upsets any claims to genuine Hadean life. There has also been a physical stumbling block to the notion that life may have originated and thrived during the Hadean: the bombardment record.

While oxygen-isotope data from 4.4 Ga zircons hints strongly at subsurface and perhaps surface water on Earth at that time, continued accretion of large planetesimals would have created the hellish conditions associated with the name of the first Eon in Earth's history. Liquid water is essential for life to have formed, on top of a supply of the essential biological elements C, H, O, N, P and S. The sheer amount of interstellar dust that accompanied the Hadean impact record would have ensured fertile chemical conditions, but would the surface and near-surface of the early Earth have remained continually wet? Judging by the lunar surface and that of other bodies in the solar system, after the cataclysmic events that formed the Moon, many Hadean impacts on Earth were in the range of 100 to 1000 km across, with a Late Heavy Bombardment (LHB)that not only increased the intensity of projectile delivery but witnessed the most energetic single events such as those that created the lunar *maria* and probably far larger structures on Earth. The thermal energy, accompanied, by incandescent silicate vapour ejected from craters, may have evaporated oceans and even subsurface water with calamitous consequences for early life or prebiotic chemistry. Until 2017 no researchers had been able to model the energetic of the Hadean convincingly.

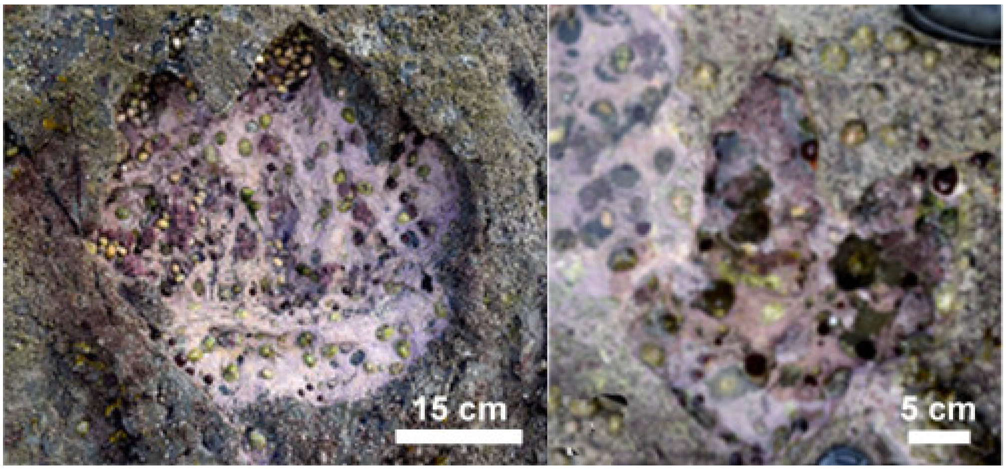
After assessing the projectile flux up to and through the LHB, and the consequent impact heating Bob Grimm and Simone Marchi of the Southwest Research Institute in Boulder, Colorado modelled the likely thermal evolution of the outer Earth through the Hadean. This allowed them to calculate the likely thermal gradients in the near-surface, the volumes of rock each event would have affected and the times taken for cooling after impacts (Grimm, R.E. & Marchi, S. 2018. Direct thermal effects of the Hadean bombardment did not limit early subsurface habitability. *Earth and Planetary Science Letters*, v. **485**, p. 1-9; doi:10.1016/j.epsl.2017.12.043). They found that subsurface 'habitability' would have grown continuously throughout the Hadean, even during the worst events of the LHB. Sterilizing Earth and thus destroying and interrupting any life processes could only have been achieved by ten times more projectiles arriving ten times more frequently over the 600 Ma history of the Hadean and LHB. Although surface water may have been evaporated by impact-flash heating and vaporized silicate ejecta, the subsurface would have been wet at least somewhere on the early Earth. Provided it either originated in or colonised surface sedimentary cover it would have been feasible for life to have survived the Hadean. However, nobody knows how long it would have taken for the necessary accumulation of prebiotic chemicals and to achieve the complex sequence of processes that lead to nucleic acids encapsulated in cells and thus self-replication and life itself.

When dinosaurs roamed the Western Isles (*April 2018*)

The Isle of Skye off the northwest coast of Scotland is known largely as a prime tourist destination, such as Dunvegan Castle with a real clan chief (The MacLeod of MacLeod) and its Faerie Flag; Britain's only truly challenging mountains of the Black Cuillin; and, of course, the romantic connection with the Young Pretender, Charles Edward Stuart and his escape, in drag, from the clutches of the Duke 'Butcher' Cumberland, hence the Skye Boat Song. Geologists know it best for its flood basalts with classic stepped topography and the exhumed guts of a massive central volcano (the Cuillin), relics of the Palaeocene-Eocene (62 to 54 Ma) North Atlantic Large Igneous Province. The spectacular Loch Coruisk, a glacial corrie drowned by the sea, exposes the deepest part of the main magma chamber. It is also the lair of Scotland's lesser known Monster, the dread *Each Uisge* (Water Horse). Yet evidence is emerging for the former presence in the Hebrides of other, more tangible monsters.

Loch Coruisk and the Cuillin Hills, Isle of Skye, Scotland, UK (credit: Wikipedia)

Skye's great volcanic edifice rests on Mesozoic sedimentary rocks including shallow-water muddy limestones of the Great Estuarine Group of Middle Jurassic (Bathonian, 174–164 Ma) age. For dinosaur specialists this is of the time when meat-eating theropods and herbivorous sauropods began growing to colossal sizes. Yet the Bathonian is notable for its global paucity in well exposed terrestrial and near-shore sedimentary sequences. Easily accessible, the Skye Bathonian sequence is much visited and has yielded a rich, though generally fragmentary fauna. A group of recent visiting palaeontologists from the University of Edinburgh, the Chinese Academy of Sciences and Skye's Staffin Museum have discovered an extensive tract of wave-cut platform on the east shore of the Trotternish Peninsula where lagoonal carbonate muds were trampled by several dinosaurs that left around 50 tracks (dePolo, P.E. *et al*. 2018. A sauropod-dominated tracksite from Rubha nam Brathairean (Brothers' Point), Isle of Skye, Scotland. *Scottish Journal of Geology*, online; doi:10.1144/sjg2017-016).

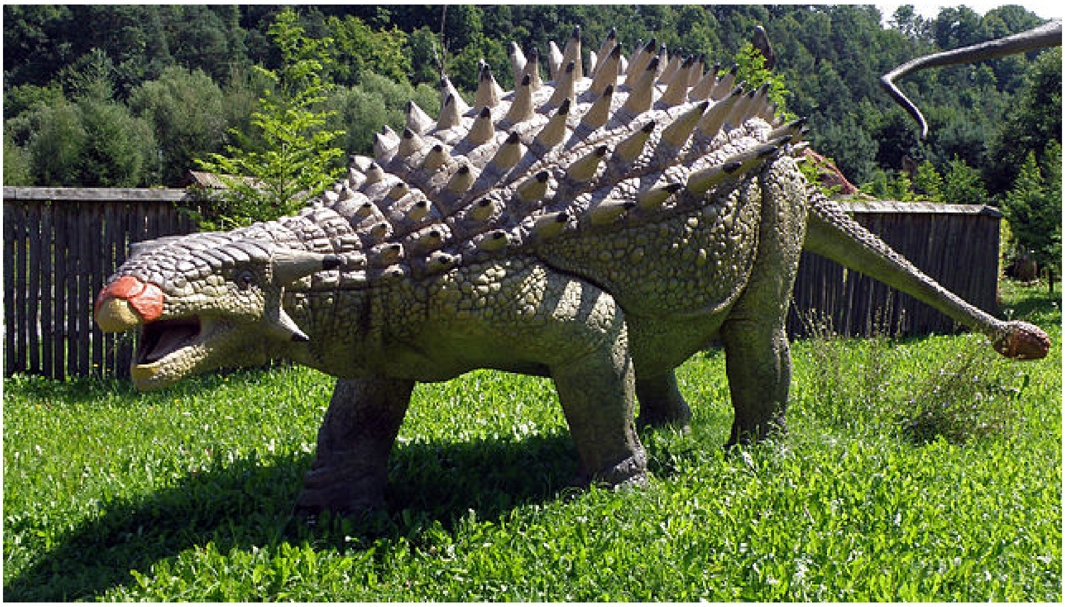


Dinosaur foot prints from Skye. Left example of a sauropod rear-foot print; right theropod. (credit dePolo, P.E. et al. 2018, modified from Figs 8 and 9a)

Some are of medium-sized sauropods (either *Parabrontopodus* or *Breviparopus* – both names for footprints rather than any genus of dinosaur) whose crudely elephant-like footprints are up to 0.5 m across (the largest, from Western Australia, are about 1.7 m across). Although there are fragmentary dinosaur bones from the same strata, assigning the footprint to a known species is not possible. However, foot size can be used to estimate how high the creatures' hips stood (2 to 2.5 m): hefty beasts but not the true giants of later times A variety of three-toed, clawed, somewhat bird-like, footprints also occur. They are assigned to probably bipedal carnivores or theropods. Variation in foot size suggests a range of hip-height from about 0.9 to 2 metres, so these carnivores would have been pretty formidable.

Mystery of upside-down dinosaurs resolved (*May 2018*)

Remains of ankylosaurs, a family of heavily armoured dinosaurs, occur in sedimentary sequences that range in age from early Jurassic to the close of the Cretaceous. Their defences seem almost impregnable, being constructed of thick, fused scales, often bearing formidable spines, which covered them completely. They bore a crude resemblance to modern armadillos apart from the fact that they were unable to roll-up defensively. In some species the rigid tail bears a large, knob of scale tissue. At up to 3 m long, were the tail to be swung it would have packed bone-cracking momentum. Interestingly, to a poorly sighted predator the club may have been mistaken for the animal's head at the end of a long neck, so perhaps it lured a potential assailant within range of its devastating power. The largest ankylosaur, from the Cretaceous of western Canada, was the size of a small bus, up to 8m long, 1.5 m wide, standing 1.7 m high and weighing in at around 5 to 8 t. Such dimensions would have made it almost impossible to be bitten, even by the largest predatory dinosaurs, and difficult to turn over. Their teeth show that ankylosaurs were herbivorous, and their somewhat bulbous bodies almost certainly contained a massive digestion system.

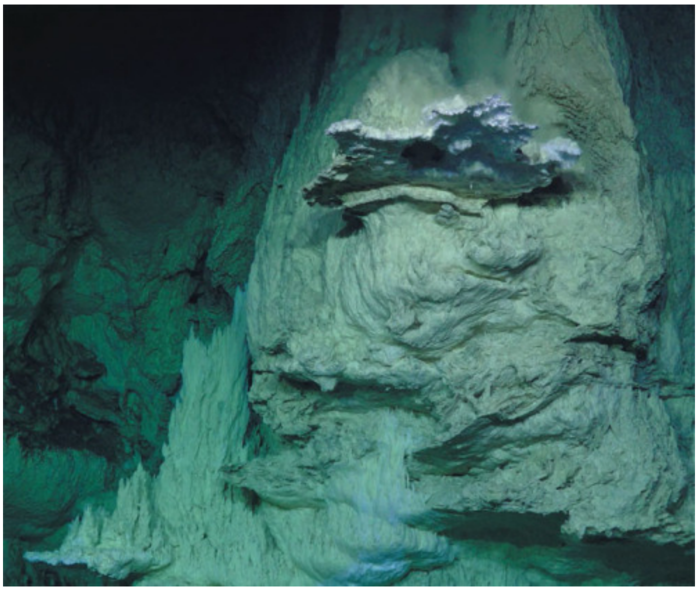


Reconstruction of Ankylosaurus at the JuraPark Bałtówin, Poland (credit: Wikipedia)

The mystery lies in the fact that most ankylosaur fossils are found lying on their backs. Early dinosaur aficionados suggested a tendency for the lumbering beasts to tumble down slopes and become stranded on their backs, so to die miserably. Such clumsiness is hardly a positive characteristic of evolutionary fitness for such a long-lived group, and, besides, the sedimentary formations in which they are found indicate very gentle slopes. So, were they flipped by dextrous predators, as imagined in some early films purporting to look to the distant past? Probably not, for most well preserved fossils show no sign of bites or gnawing. From a study of 36 late-Cretaceous ankylosaurs from Alberta four Canadian and US palaeontologists (Mallon, J.C. *et al*. 2018. A "bloat-and-float" taphonomic model best explains the upside-down preservation of ankylosaurs. *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. **497**, p. 117-127; doi:10.1016/j.palaeo.2018.02.010) support the idea of their carcases or even living animals having been picked up by flood waters when their high centre of gravity would have flipped them upside down. Bloating through decay might then allow them to be transported large distances. Unsurprisingly, their conclusions rest on model simulations.

Oceanic hydrothermal vents and the origin of life (*November 2018*)

A range of indirect evidence has been used to suggest that life originated around hydrothermal vents deep in the oceans; for instance there are signs of early organic matter in association with Archaean pillow lavas. One particularly persuasive observation is that a number of proteins and other cell chemicals are constructed around metal sulfide groups. Such sulfides are common around hydrothermal 'smokers' associated with oceanic rift systems. Moreover, Fischer-Tropsch reactions between carbon monoxide and hydrogen produce quite complex hydrocarbon molecules under laboratory conditions. Such hydrogenation of a carbon-bearing gas requires a catalyst, a commonly used one being chromium oxide (see *Abiotic formation of hydrocarbons by oceanic hydrothermal circulation* May 2004). It also turns out that fluids emitted by sea-floor hydrothermal systems are sometimes rich in free hydrogen, formed by the breakdown of olivine in ultramafic rocks to form hydroxylated minerals such as serpentine and talc. The fact that chromium is abundant in ultramafic rocks, in the form of its oxide chromite, elevates the possibility that Fischer-Tropsch reactions may have been a crucial part of the life-forming process on the early Earth. What is needed is evidence that such reactions do occur in natural settings.



A white carbonate mound forming at the Lost City hydrothermal vent field on the Mid-Atlantic Ridge (Credit: Baross 2018)

One site on the mid-Atlantic ridge spreading centre, the Lost City vent field, operates because of serpentinisation of peridotites exposed on the ocean floor, to form carbonate-rich plumes and rocky towers; 'white smokers'. So that is an obvious place to test the abiotic theory for the origin of life. Past analyses of the vents have yielded a whole range of organic molecules, including alkanes, formates, acetates and pyruvates, that are possible precursors for such a natural process. Revisiting Lost City with advanced analytical techniques has taken the quest a major step forward (Ménez, B. *et al*. 2018. Abiotic synthesis of amino acids in the recesses of the oceanic lithosphere. *Nature*, v.. **564**, p. 59-63; DOI: 10.1038/s41586-018-0684-z). The researchers from France and Kazakhstan focused on rock drilled from 170 m below the vent system, probably beyond the influence of surface contamination from living organisms. Using several methods they detected the nitrogen-containing amino acid tryptophan, and that alone. Had they detected other amino acids their exciting result would have been severely tempered by the possibility of surface organic contamination. The formation of tryptophan implies that its abiotic formation had to involve the reduction of elemental nitrogen (N_2) to ammonia (NH_3). Bénédicte Ménez and colleagues suggest that the iron-rich clay saponite, which is a common product of serpentine alteration at low temperatures, may have catalysed such reduction and amino-acid synthesis through Friedel–Crafts reactions. Fascinating as this discovery may be, it is just a step towards confirming life's abiogenesis. It also permits speculation that similar evidence may be found elsewhere in the Solar System on rocky bodies, such as the moons Enceladus and Europa that orbit Saturn and Jupiter respectively. That is, if the rock base of hydrothermal systems thought to occur there can be reached.

Related article: Baross, J.A. 2018. The rocky road to biomolecules. *Nature*, v. **564**, p. 42-43; DOI: 10.1038/d41586-018-07262-8.

Pterosaurs had feathers and fur (*December 2018*)

Pterosaurs, which include the pterodactyls and pteranodons, were the first vertebrates to achieve proper, flapping flight. In the popular imagination they are regarded as 'flying dinosaurs', whereas the anatomy of the two groups is significantly different. The first of them appeared in the Upper Triassic around 235 Ma ago, at roughly the same time as the earliest known dinosaurs. The anatomical differences make it difficult to decide on a common ancestry for the two. But detailed analysis of pterosaur anatomy suggests that they share enough features with dinosaurs, crocodiles and birds for all four groups to have descended from ancestral archosaurs that were living in the early Triassic, and they survived the mass extinction at the end of that Period. Birds, on the other hand, first appear in the fossil record during the Upper Jurassic 70 Ma later than pterosaurs. They are now widely regarded as descendants of early theropod dinosaurs, which are known commonly to have had fur and feathers.

Pterosaurs leapt into the public imagination in the final chapter of Sir Arthur Conan Doyle's *Lost World* with a clatter of 'dry, leathery wings' as Professor George Challenger's captive pterodactyl from northern Brazil's isolated Roraima tepui plateau made its successful bid for escape from a Zoological Institute meeting in Queens Hall. Yet, far from being leathery, pterosaurs turned out, in the late 1990's, to have carried filamentous pycnofibres akin to mammalian hair. Widespread reports in the world press during the week before Christmas in 2018 hailed a further development that may have rescued pterosaurs from Conan Doyle's 1912 description before it sprang from its perch:

> I*t was malicious, horrible, with two small red eyes as bright as points of burning coal. Its long, savage mouth, which it held half-open, was full of a double row of sharp-like teeth. Its shoulders were humped, and round them was draped what appeared to be a faded grey shawl. It was the devil of our childhood in person.*

Two specimens from the Middle to Upper Jurassic Yanliiao lagerstätte in China show far more (Yang, Z. and 8 others 2018. Pterosaur integumentary structures with complex feather-like branching. *Nature Ecology & Evolution*, v. **3**, p. 24-30; DOI: 10.1038/s41559-018-0728-7). Their pycnofibres show branching tufts, similar to those found in some theropods dinosaurs, including tyrannosaurs. They also resemble mammalian underfur fibres, whose air-trapping properties provide efficient thermal insulation. Both body and wings of these pterosaurs are furry, which the authors suggest may also have helped reduce drag during flight, while those around the mouth may have had a sensory function similar to those carried by some living birds. Moreover, some of the filaments contain black and red pigments.

Artist's impression of a Jurassic pterosaur from China (Credit: Yang et al 2018; Fig. 4)

Pterosaurs may have independently developed fur and feathers; a case of parallel evolution in response to similar evolutionary pressures facing dinosaurs, birds and mammals. Alternatively, they may have had a deep evolutionary origin in the common ancestors of all these animal groups as far back as the Upper Carboniferous and Lower Permian.

Related articles: *Nature* Editorial 2018. Fur and fossils. *Nature*, v. **564**, p. 301-302; DOI: 10.1038/d41586-018-07800-4; King, A. 2018. Pterosaurs sported feathers, claim scientists (The Scientist); Conniff, R. 2018. Pterosaurs just keep getting weirder (Scientific American); New discovery pushes origin of feathers back by 70 million years (Science Daily)