GEOBROWSER

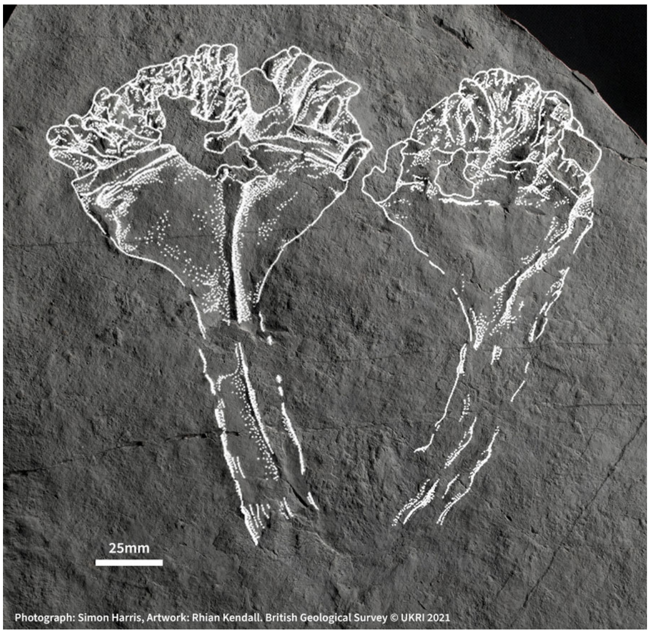
Charnwood Forest makes national news

There has been a long-running debate over precisely when complex organisms belonging to our own kingdom, the Animalia, first evolved. In recent years palaeontologists around the world had proposed animal-like characteristics for certain late Precambrian micro- and macrofossils and trace fossils, but there was no clear evidence for an ancestral link between these and the proliferation of animal life that occurred in earliest Cambrian times. In July 2022, however, the BBC's News at Six featured a stunning fossil discovery made in Charnwood Forest. A Press Release by the BGS had posted details of a new fossil with quite definite, cnidarian (coral-like) features found in the Precambrian strata of Charnwood Forest, and dated at about 26 million years *before* the Early Cambrian diversification. The specimen has been named *Auroralumina attenboroughii,* after the famous Leicestershire-born naturalist, and its zoological affinities are explained in a paper by Dunn *et al* published in the August 2022 edition of Nature (*nature.com/natecolevol*).

This is not the first time that Charnwood Forest has turned palaeontology on its head. Whereas it had always been thought that only algal, microbial or simple-celled life could have existed before the Cambrian Period, this changed in 1957 when a schoolboy, Roger Mason, brought attention to a large frond-like fossil impression (independently discovered by a schoolgirl, Tina Negus, a year earlier) on a steeply dipping Precambrian bedding plane. He took a 'brass rubbing' of it along to Trevor Ford (biography in *Mercian Geologist* for 2020) at Leicester University, who then made further discoveries at the same site. His landmark publication (*Ford 1958, Proc. Yorkshire Geol. Soc. 31, 211–217*) proved that complex and diverse, albeit enigmatic, life-forms did indeed flourish in Precambrian time. Palaeontologists around the world realised that strata containing similar fossils must be Precambrian, rather than Cambrian as previously thought, and renewed searching led to the discovery of many new fossil assemblages, now known as the 'Ediacara biota'. Meanwhile in Charnwood Forest more new species were being found by Trevor and colleague Helen Boynton (described in *Mercian Geologist* for 1995). These new fossiliferous localities yielded a relatively restricted assemblage, compared with what was being found around the world. Nonetheless, thanks largely to Helen and Trevor's efforts, and especially to the former's founding of the Charnia Research Group, Charnwood Forest continued to have a significant profile.

It became a sort of Mecca that Precambrian palaeontologists from around the world simply had to visit, and an international 'Charnia Symposium' held at Leicester in 2007 included a field excursion to Ford and Mason's famous fossil site. The delegates urged that more work should be done, and later that year a British Geological Survey team found several new specimens, from which silicone rubber moulds were taken. The plaster casts of these were then used to attract 'seed' funding from the BGS and English Nature and a major project was duly mounted in 2008. Thanks to crucial climbing expertise provided by Alan Weightman and Frank Ince on the steeply dipping bedding planes, the contractor (GeoEd) made a series of carpet-sized moulds, sufficient to cover some 100 m^2 of bedding plane (*Wilby et al, BGS Earthwise magazine 26, 2010).* From these moulds they produced dozens of large-area plaster casts, enabling whole fossil communities to be examined in well-lit laboratory conditions at the BGS. The results were staggering, with over a thousand more fossils discovered (*Wilby et al, Geology 39/7, 2011*), as well as new species including the one reported here.

What makes *Auroralumina attenboroughii* so special according to Dunn *et al* is that it '*…displays a distinctive combination of characters that is not present in other fossil taxa… shedding light on the early evolution of a number of key cnidarian traits.*' They go further by suggesting that the fossil confirms that crown-group cnidarians must have co-existed with the oldest assemblage of the Ediacaran macrobiota. It is therefore *'...the most ancient fossil that can be reliably ascribed to the crown-group of any living animal phylum'.* In other words, *Auroralumina* is the most distant ancestor to a living animal species that has yet been recorded. The researchers note that modern cnidarians, like corals, use tentacles to catch food and say that '*...the presence of a dense tentacular crown would support a similar life-habit for* Auroralumina*'*. The implications



Artist's outline of Auroralumina attenboroughii *over an image of the fossil reproduced as a plaster cast. This interprets the specimen as a cnidarian, with tentacle-like processes surmounting the left-hand branch. (Photograph: Simon Harris; artwork by Rhian Kendall; British Geological Survey, as featured in Dunn* et al*, 2022)* are that other cnidarian-type animals must have been present in the late Precambrian (Ediacaran), as well as water-borne planktonic material from other species on which *Auroralumina* fed.

One perplexing feature of *Auroralumina* is that it is totally unlike any of the surrounding, more typically frondose Precambrian fossils on the bedding plane (e.g. *Charnia*). These latter are still of uncertain taxonomic affinity and thus do not fall into any known crown-group or kingdom. They appear to have lived at depth, anchored to the Precambrian sea-floor before being knocked over by a sediment-laden submarine turbidity current. In the BGS Press Release, Frankie Dunn suggests that because *Auroralumina* lies at an odd angle to the other, current-aligned frondose fossils it is probably not *in situ,* having been washed in from higher up on the palaeoslope during the same event. So it seems that in Charnwood the late Precambrian biota was probably depth-tiered, featuring at least one species of Animalia whose development may have been favoured by environmental factors such as the availability of nutrients and light.

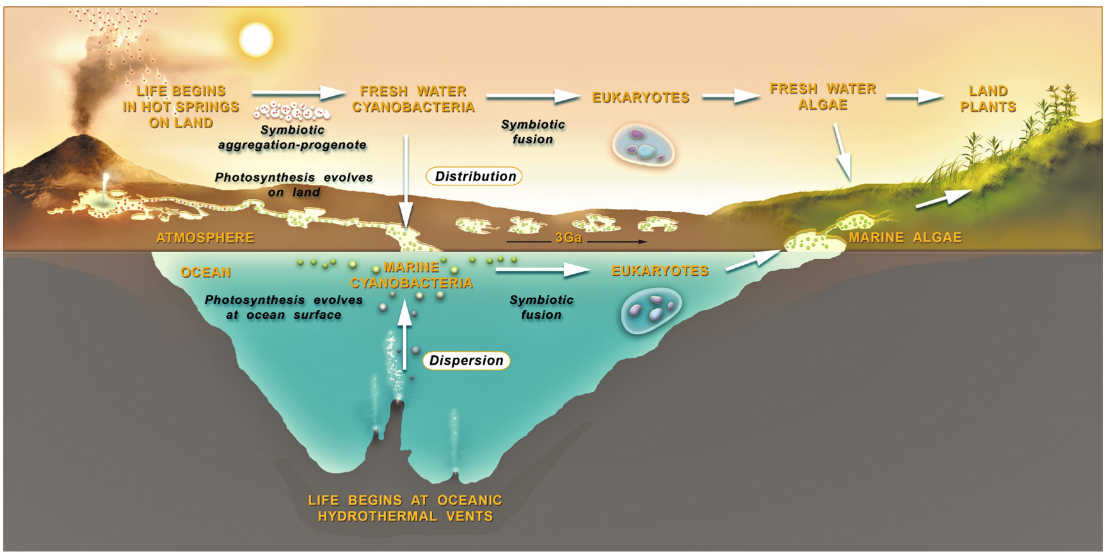
Geological analogues help the search for alien life

The question of how on Earth simple life-forms arose more than 3.5 billion years ago, from what must have been random assemblages of elements and molecules, continues to be a major topic of research and conjecture. The answer to this is becoming all the more pressing, however, because earthly environments are increasingly being used as analogues in the search for life on other planets or their moons, as witnessed by the many recent articles published in the journal *Astrobiology*.

Fortunately, advances in molecular chemistry and biology are beginning to provide clues to the origin of life, at least on Earth, and although there are a plethora of theories the consensus now revolves around two types of watery environment, summarised in the cartoon by Damer & Deamer (*Astrobiology, 2020: doi.org/10.1089/ast.2019.2045*). One of these was favoured by Darwin (1871), who with great prescience speculated how life may have started in a letter to his friend J. D. Hooker: '*But if (& oh what a big if) we could conceive in some warm little pond with all sorts of ammonia & phosphoric salts,—light, heat, electricity & etc. present, that a protein compound was chemically formed, ready to undergo still more complex changes'*. But he could never have imagined the second candidate, in which the necessary 'heat, electricity & etc' could be found at great depths around hydrothermal vents occurring along mid-ocean ridge systems.

In discussing the relative merits of oceanic versus terrestrial environments, Damer & Deamer consider that in the case of the former, simple microbial or bacterial life could have been synthesised in the warm conditions existing at submarine oceanic hydrothermal vents, which are charged with elements and also emit gases such as methane and carbon dioxide. If so, however, the necessary metabolic processes would at first have used the same energy as today's anaerobic microbial populations that do not require oxygen (respiration) or light (photosynthesis). Such energy would have come from electrons transported from substrates containing hydrogen or hydrogen sulphide to oxidants containing sulphate, ferric iron or carbon dioxide.

As an alternative, Darwin's 'warm little pond' idea is embodied in the 'Hot Spring Hypothesis for the Origin of Life' summarised by Damer & Deamer. The argument here is that if life developed in terrestrial hot springs, perhaps similar to the famous modern examples at the Yellowstone National Park, there would be an obvious evolutionary pathway to terrestrial, photosynthesising biota. Ancient freshwater life would at first be synthesised geochemically, with the necessary carbon provided by fumarolic gases such as methane, but also perhaps in complex molecules sourced from the carbonaceous extraterrestrial debris that would have littered the Earth's surface following cessation of the Hadean meteorite bombardment about 3.8 billion



Alternative scenarios for the origin of life on Earth (Source: Damer & Deamer, 2020) years ago (see *Geobrowser* for 2021). Other essential elements such as iron, and the phosphorous mentioned by Darwin, could be contributed from terrestrial erosion. Damer & Deamer suggest that such early life would have been continuously exposed to sunlight, so could develop photosynthesis, while exposure to damaging ultraviolet radiation would have been mitigated if the organisms were hypolithic i.e. living beneath rocks or a thin regolith. On Earth, compelling evidence that microbial life thrived in hot springs 3.5 billion years ago is found in the Dresser Formation of the Pilbara region, Western Australia (*Djokic et al, 2017; Nature Communications, 8*), where fossil stromatolites are interpreted to have developed in waters ponded within a volcanic caldera affected by voluminous hydrothermal fluid circulation.

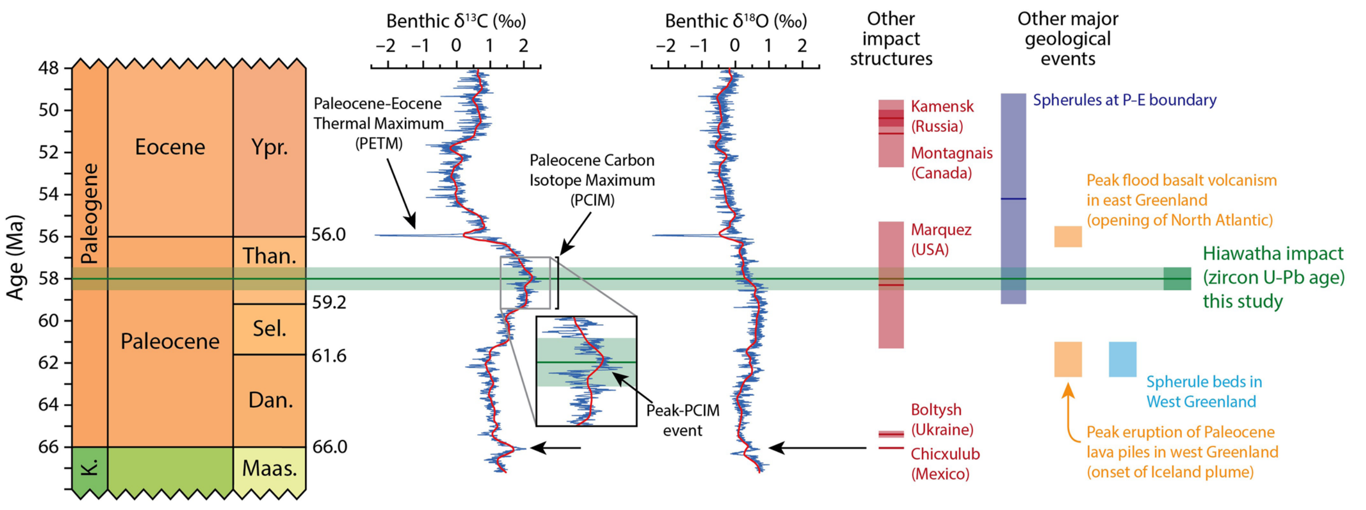
With respect to life elsewhere in the solar system, both environmental analogues could have some relevance. The 'hot spring' model – Darwin's 'warm little pond' – possibly applies to Martian conditions during that planet's 'warm and wet' phase, which most probably terminated when it lost most of its 'greenhouse gases' around 3.5 billion years ago. Before that, a combination of ponded meltwaters and hydrothermal activity, perhaps within a caldera or volcano flanks, might well have replicated a Pilbara-type environment. In that case, perhaps the best chance of finding such evidence would be in exposed Martian strata containing fossilised 'hard' carbonate build-ups such as stromatolitic domes or layers.

The deep oceanic-type model for life seems less applicable to Mars, which never had Earth-type plate tectonics. Remarkably, however, live organisms could exist today in the more outer reaches of the solar system. For example, in 2005 the Cassini probe found that frozen water ejected into space from geysers emanating from Saturn's icy moon, Enceladus, contained carbon dioxide, methane, ammonia and either carbon monoxide or nitrogen gas, along with salts and silica, indicative of formation temperatures above 90 degrees C (*e.g. Nasa Science Enceladus website*). This suggests that the moon's icy cap could today be covering oceans warmed by hydrothermal vent-type activity, perhaps replicating at least the physical (if not geological) conditions which are incubating diverse life along our own mid-ocean ridge systems. Yet another mission, mounted by the European Space Agency (Project JUICE), was successfully launched in April this year. It will seek out possible life-supporting conditions, including liquid water and a source of energy, beneath the icy surfaces of Jupiter's moons: Europa, Ganymede and Callisto. Not far behind it, another Nasa probe, planned to launch in 2024, will study Europa.

Greenland asteroid age — and a Scottish connection?

In 2016 an aerial survey using ice-penetrating radar imaged a 31 km-diameter crater beneath the Hiawatha Glacier of northern Greenland. As reported in *Geobrowser* for 2019, this feature shows all the geometrical characteristics of an impact from a very large asteroid; but its age has provoked much controversy. While the original discoverers (*Kjaer et al, Science Advances, 2018; doi: 10.1126/sciadv.aar8173)* were circumspect, many subsequent workers leapt to the suggestion that it occurred very recently and was perhaps the trigger for the dramatic climatic cooling between 12,836 and 12,815 cal BP that ushered in the Younger Dryas period, which had a major influence on human development. Such speculation seemed reasonable since across four continents, archaeological investigations of Younger Dryas Boundary (YDB) sites have found abundant evidence for extra-terrestrial devastation (see *Geobrowsers* for 2018 and 2022).

The thick Arctic ice cover posed obvious problems for obtaining age-dating material, so the researchers decided to sample sediments that had washed out from

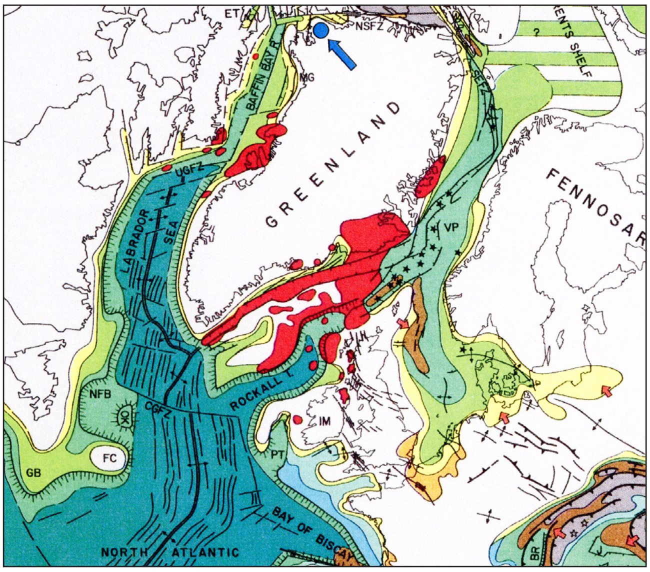


The new age for the Hiawatha impact structure in the context of early Paleogene chronostratigraphy, carbon and oxygen isotope variations and impact events (Source: Kenny et al, 2022) beneath the glacier between 5 and 10 km from the edge of the buried crater (*Kenny et al, 2022; doi: 10.1126/sciadv.abm2434*). This approach was vindicated by finds of sand grains containing impact-diagnostic features, such as planar deformation features in quartz, and step-heating analysis using $^{40}Ar/^{39}Ar$ laser age-dating was performed on these. Two pebbles with glassy, melt-type matrices containing clasts showing 'toasted' and deformed quartz together with 'chequerboard' plagioclase feldspars were also found, and these were subjected to U-Pb zircon dating. The latter is considered the most robust age of the impact, which occurred during the mid- to later part of the Paleocene Epoch, at 58.99 +/- 0.54 million years ago.

The impact was therefore very much older than previously thought, and is clearly unrelated to the YDB extra-terrestrial event. Considering the 1.5 km diameter size estimated for the 'Hiawatha' asteroid, however, some sort of climatic crisis, or recognisable global response seems likely, albeit not as apocalyptic as that for the dinosaur-killing 10 km-wide Chicxulub impactor (Yucatan Peninsula) which occurred 7 million years before. In addressing this, Kenny *et al* note that the Hiawatha impact is distinguishably older than the ~56-Ma date for the initiation of the Paleocene-Eocene Thermal Maximum. Its age does, however, overlap with that currently estimated for the 12.7 km diameter Marquez impact structure in Texas, suggesting a possible global-scale 'cluster' bombardment. With this in mind, it is noteworthy that the Hiawatha and Marquez events coincide with a ~58-Ma negative step in (oceanic) benthic $\delta^{13}C$ values, followed by a positive excursion, together known as the peak-Paleocene Carbon Isotope Maximum. This initiated a warming trend featuring a long-term decline in $\delta^{13}C$ values, possibly due to less favourable conditions for sequestration of organic carbon matter in the oceans or on land.

... is there a Scottish link?

Although there may have been a global response to such a large impact, the geological evidence for what Kenny *et al* call a 'Hiawatha association' could be present on our own doorstep. At the time of impact, Atlantic rifting had only just started to propagate northwards, placing Britain considerably closer to the Greenland crater than it is now, so it is of interest that two sites with features supporting an impact origin have been discovered at the base of the Paleocene lava successions on south-eastern Skye. In a 2017 paper by Drake *et al* (*Geology 46/2, 172–41),* both impact layers include unmelted vanadium-rich osbornite (TiVN) and niobium-rich osbornite (TiNbN), which so far have only been found among the unmelted impactor mineralogy from the Chicxulub crater. They also contain reidite (a high-pressure zircon polymorph only found naturally at meteorite impact sites), carbon-bearing native iron spherules, and shock-melted glass in quartz.



North Atlantic palaeogeography at about the time of the Hiawatha asteroid impact (position arrowed). The red-coloured areas represent the distribution of Paleocene lavas and volcanic centres related to activity from the proto-Icelandic mantle plume. (Source: P. A. Zeigler, 1988, AAPG Memoir 43, plate 17)

The paper concludes that the causative impact cannot have been older than a date of 61.54 ± 0.42 Ma (^{40}Ar-^{39}Ar method), obtained on a basalt block within an impact-breccia layer at Site 2. Their suggested younger limiting age is, however, controversial as it is not based on direct, site-specific dating of the lavas which conformably overlie the impact layer at their Site 1. Although they quote an age of 60.00 ± 0.23 Ma, determined previously by Chambers *et al* (*Lithos, 79, 2005, 367–84*), the latter considered this to be only the start of volcanism on Skye and other Hebridean islands. In this respect it is noteworthy that the Site 1 lavas occur in close proximity to, and thus were possibly fed by the Cuillin Hills central intrusive complex, from which a date of 58.91 ± 0.08 Ma was obtained by Hamilton *et al* 1998 (*Nature 394, 260–3)*. Added to this are a number of other age dates, summarised by Chambers *et al,* suggesting that the Scottish Paleocene volcanism most probably lasted between about 60 and 58 Ma — neatly bracketing the timing of the Greenland impact event.

Back cover photographs

Images of ground subsidence by Tony Waltham. Clockwise from top left: house in San Francisco subsided due to drainage of peat, and after the road had been restored to original level; well casing in Mexico City, protruding from ground after regional subsidence due to groundwater abstraction; failure over inadequate foundations in Kashgar where house extension was built on the roadside pavement; The Bund in Shanghai, the embankment now below river level due to groundwater extraction; Leaning Tower of Pisa, stabilized since 2001 by careful extraction of clay from beneath the left side; Crooked House inn near Wolverhampton tilted by mining subsidence on one side and not the other, prior to being burned down in 2023.