GEOBROWSER

Explosive happenings in Siberia

In Siberia, methane has been quietly bubbling to the surface since at least the 1960s according to Bogoyavlensky *et al.* (*2021, doi.org/10.3390/geosciences 11020071*). It has mainly been emanating from natural reservoirs in thermokarst lakes (deep, water-filled circular depressions on the permafrost surface) and, to a lesser extent, from rivers and marine embayments. Since 2013, however, the phenomenon has taken on a new and dramatic appearance in the form of giant explosion craters that are now appearing across the peninsulas of Yamal, Gydan, Yakutia and Chukotka.

The first detailed descriptions using satellite images and expedition data were given by Bogoyavlensky (*Oil and Drilling, 2014, no 9*). Although the craters were surrounded by frost mounds, these did not exhibit the large cracks typical of frost-heave structures such as *pingos*. Nor would the latter be associated with the fire, smoke and an earthquake reported in September 2013 in the vicinity of a new crater. That crater measured about 4 m across and over 60 m deep, and explosive activity was confirmed by fragments of rock found up to 900 m away. Cavities seen in the walls of explosion craters visited before melt-water had filled them are thought to be the channels through which the gas had issued.

Methane gas blowout crater formed in 2020 on the Yamal Peninsula (Source: WION)

In their 2021 article, Bogoyavlensky *et al.* suggested that methane accumulations in the upper part of the permafrost section, which includes thermokarst cavities, built up a head of pressure sufficient to first up-dome and then explosively punch through the permafrost overburden. The methane leakage was probably initiated by warm fluids and gases rising from depth and this, when combined with the surficial effects of global warming, was sufficient to weaken the strength of the permafrost, particularly along local fault zones. The ultimate source of this methane is still somewhat conjectural: it was commonly assumed that it had been locked-in to permafrost developed in Siberian wetlands, but other possibilities include gas hydrate dissociation or natural gas deposits in permafrost.

Support for the further suggestion that at least some methane is filtering up from the economically important Cenomanian (Late Cretaceous) strata occurring at depths of 520–700 m, as well as from reservoirs in Palaeozoic rocks at 3250–3450 m depth, comes from the study by Froitzheim *et al.* (*2021, doi: 10.1073/pnas.2107632118*). Using satellite-based spectroscopic measurements of airborne natural methane concentrations following the 2020 Siberian heat-wave, they found that significantly elevated concentrations occurred in two areas where the exposed bedrock consisted of Palaeozoic limestone formations. It seems likely that the methane has risen from bedrock reservoirs both within and below the permafrost zone, but had been sealed-in by a mixture of ice and frozen gas hydrate. Due to climatic warming, however, this permafrost seal has been weakened, causing thawing which is allowing the gas to escape. The elevated concentrations not only coincided with the extreme heat-wave, but persisted for months after.

Measurements and model calculations are now underway to find the rate of natural methane release from exposed bedrocks. Whatever the actual source(s) of the methane emissions, however, its escape is a matter of some concern since the gas has 80 times the warming power of carbon dioxide over the first 20 years after it reaches the atmosphere. In Siberia, calculations made in 2013 suggested that global warming was thawing the permafrost layers to the extent that some 17 million tonnes of the gas was escaping annually (*Live Science, July 2017*). Moreover, the rapid rate of thawing, perhaps exacerbated by wildfires of the type that now regularly ravage the Siberian Taiga, means that all of the permafrost could disappear by 2100 (*Moscow Times Report, July 2021*). This has prompted the regular issue of warnings such as that by Froitzheim *et al.*, who note that "*The estimated amounts of natural gas in the subsurface of North Siberia are huge. When parts of this will be added to the atmosphere upon thawing of the permafrost, this could have dramatic impacts on the already overheated global climate*." To this must be added the chronic 'leakage' of methane from oil and gas installations, which in Russia alone rose by 32 per cent in 2020 (*Cheryl Katz, BBC Future Planet website for August 2021*).

Multicoloured hydrogen power for UK?

The UN Climate Change Conference (COP26) held in Glasgow in 2021 was presaged by a plethora of UK Government papers, press releases and announcements of the intention to cut out 78 per cent of carbon emissions by 2035 and achieve carbon neutrality by 2050. There has been a promising start (or catch-up?): over the last decade the UK has decarbonised its electricity system at almost twice the pace of any other major economy by growing renewables six-fold and slashing the use of coal (*Drax Electric Insights Quarterly – Q3 2020*). But

to continue this progress and achieve the increasingly desirable self-sufficiency in power supply, other sources of low-carbon energy will be needed. These currently include nuclear as well as renewables such as wind, solar, and hydro/tidal power. But there is another entirely separate energy source where we lag behind other countries.

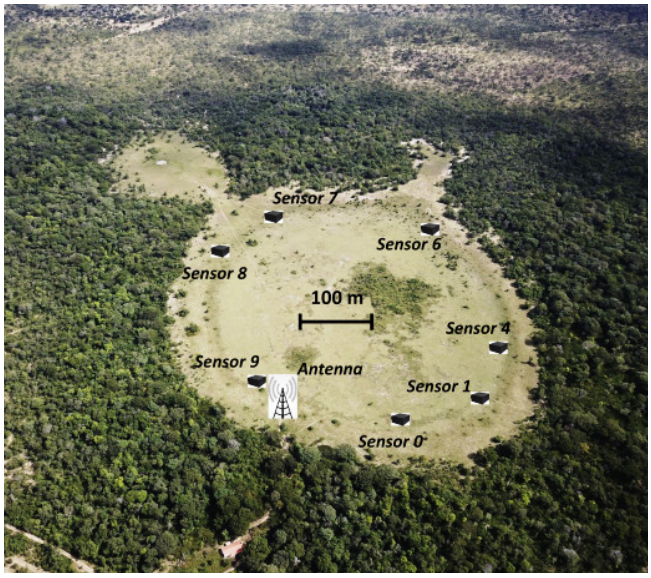
Governments, researchers and multinational companies have been turning their attention to hydrogen power as an alternative, or even a competitor, to the other low-carbon fuel sources (*e.g. J. Wood, World Economic Forum website, February 2022*). In August 2021, the UK government launched its own 120-page *Hydrogen Strategy* document, with the aim of annually producing 5GW (five billion joules per second) of low-carbon power from hydrogen by 2030. This is equivalent to the amount of gas used by three million UK households; however, the energy crisis precipitated by Russia's invasion of the Ukraine saw this ambition doubled to 10GW in the government's updated *British energy security strategy document*, published in April of this year. Pioneering domestic heating projects in the UK are currently testing the viability of using either a full hydrogen supply or blending up to 20 per cent of it with the existing natural gas network. Hydrogen can also power vehicles either from fuel cells, as used in Toyota's *Mirai* production saloon or, more cheaply, by modifying existing combustion engine technology (*e.g. JCB website*). Some doubt the economic viability of hydrogen power (*The Conversation, July 22, 2020: Hydrogen isn't the key to Britain's green recovery – here's why*), but given that hydrogen is the third most abundant element on Earth, after oxygen and silicon, there should be a ready supply. The problem stems from its propensity to form molecules with numerous other elements.

To separate 'free' hydrogen needed for power generation the technology used in the UK operates in association with natural gas production by splitting methane molecules. What is called '**grey hydrogen**' has been produced this way for many years, but it releases by-product carbon dioxide into the atmosphere. To avoid this, new plants producing '**blue hydrogen**' from methane are proposed. They will specifically capture and store the excess carbon dioxide, which surely could also be a useful industrial by-product, although US academics have pointed out that 'fugitive' emissions from blue hydrogen plants could actually eclipse the benefits of carbon storage (*Reported by J. Ambrose, Guardian website, August 2021*).

By contrast, '**green hydrogen**' production would use the planet's vast resource of water, which is split into hydrogen and oxygen by electrolysis. Favoured in the government's updated energy strategy, its 'clean' credential relies upon the electricity being supplied from a mix of wind and solar energy, and it is a potentially cheaper method because no carbon dioxide needs to be disposed of. Related to this is '**pink hydrogen**', where electrolysis uses nuclear power, and '**yellow hydrogen**' where only solar-produced electricity is used (*Petrofac website: 'The difference between green and blue hydrogen'*). The 2021 Hydrogen Strategy document proposes a mix of 23 green and 9 blue hydrogen-producing plants, with three potential areas of offshore CO_2 storage earmarked for the latter.

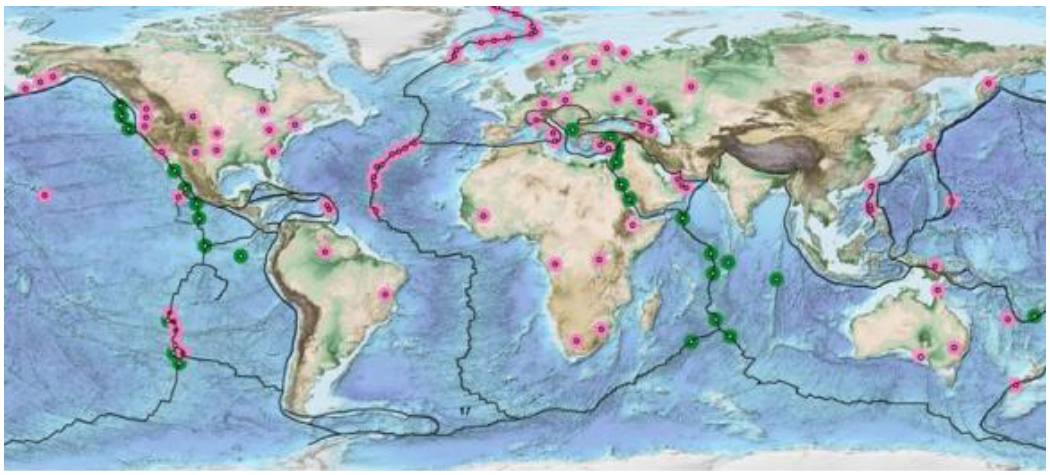
… the 'holy grail' of hydrogen power?

An as yet largely neglected resource has been given the name '**gold hydrogen**' by J. Gluyas of Durham University. This refers to naturally occurring hydrogen, which does not require any input of energy to collect once the source has been tapped (*e.g. 'Natural Hydrogen: the new frontier': Geoscientist website, March 2022*). Such free hydrogen has been known about for some 100 years, mainly because its onshore seepages commonly give rise to areas devoid of vegetation and sometimes to fires that cannot be put out. It occurs in a number of differing geological settings around the world, which are summarised in the article by Moretti & Webber (*Renewable Matter website, January 2021*).



Area of vegetation destroyed by natural hydrogen outgassing in the Sao Francisco basin of Brazil (Source: Prinzhofer et al., 2019, doi.org/10.1016/j.ijhydene.2019.01.119)

In association with methane, helium and other gases such as CO_2, hydrogen has been found issuing from hydrothermal vents along mid-ocean ridges, but it is more likely to be prospective in related on-shore settings, such as in the Afar-Red Sea area and in Iceland, where fumaroles of the central rift axis all contain hydrogen (*Combaudon et al., 2022, doi: org/10.1016/j.ijhydene.2022.01.101*), and where its extraction could be a useful by-product of geothermal heating. Up-thrusted slivers of oceanic crust have also proved prospective for natural hydrogen in Oman, the Philippines and New Caledonia. More promising are terrains underlain by cratonic rocks more than 500 million years old. For example Zgonnik (*2020, doi: org/10.1016/j.earscirev.2020.103140*) shows that a deep-seated origin is potentially the most likely explanation



Global distribution of 'free' hydrogen occurrences (pink spots) and methane derived from hydrogen (green spots) (Source: Moretti & Webber, 2021)

for the abundance of molecular hydrogen in nature, with hundreds of examples of hydrogen flows from cratonic areas that include Russia (around Moscow) and the USA (South Carolina and Kansas). One possible mechanism could be the release of H_2 from the oxidation of iron-rich rocks in old and mineral-rich basement complexes. An additional requirement, some suggest, is for cap-rocks to form a seal preventing the widespread escape of the gas. Such conditions exist at Bourakebougou, in Mali, where hydrogen gas was encountered accidentally during oil drilling in 1987. Since 2007, follow-up drilling by the Canadian company, Hydroma, has produced hydrogen from 25 wells, sufficient to power a gas turbine providing the village with free electricity.

To secure commercially significant quantities of free hydrogen, however, 'non-accidental' finds will be needed, and this will involve some entirely new systematic exploration models. One example is the (undisclosed) science behind the successful completion of an exploration well in the USA by Natural Hydrogen Energy LLC (NH2E). On their 2019 website the company point out that natural hydrogen as a renewable source of clean energy is continuously generated at depth by inorganic reactions "*that have been active for millions of years and will remain so in the future*." The Geological Society's policy and technology explainer, *Geoscience and the Hydrogen Economy* (April 2021) notes that because naturally occurring hydrogen deposits occur in geological settings that are not typically drilled or monitored for gases at present, their abundance globally is not yet accurately known. As the map shows, however, there are several potential hydrogen gas sources in European countries outside of Russia, so the exploration field is wide open, even perhaps in the UK.

Disturbingly recent cosmic disasters

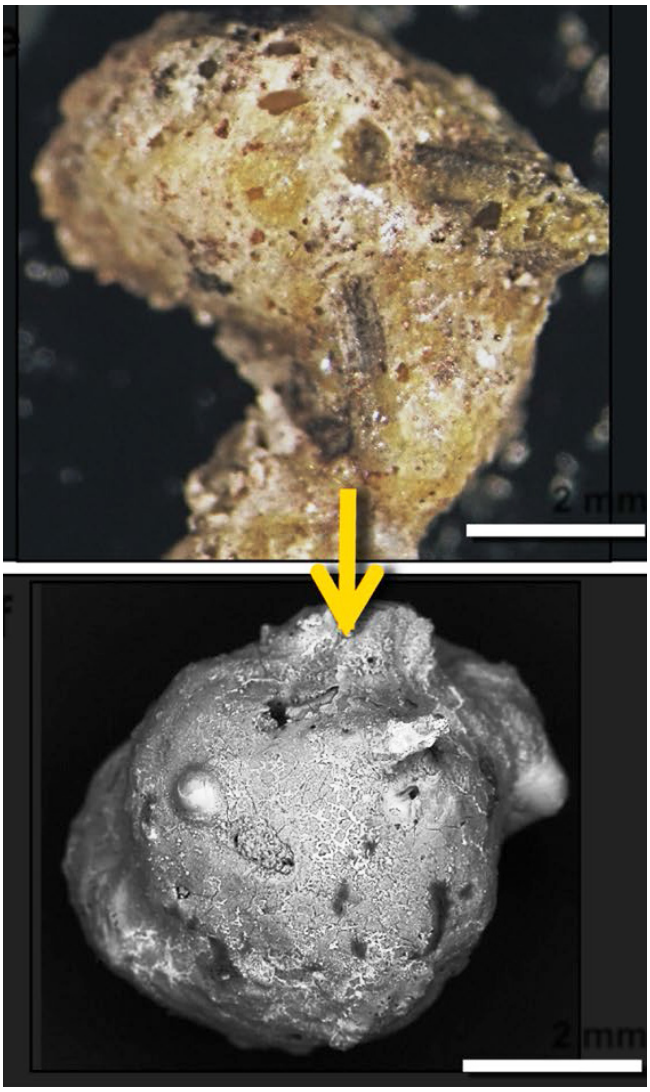
On 23 November 2021, NASA launched DART (Double Asteroid Redirection Test) on a mission to crash a small non-explosive probe into a 160 m-diameter asteroid (*Dimorphos*) orbiting around a larger body about 11 million km from Earth. The collision is scheduled for the end of September this year and will test how effectively a spacecraft impact could deflect the orbital course of some future asteroid bound for Earth (*NASA: DART mission website*). Some may think this an esoteric exercise, but then an estimated 100 metric tons of space debris falls to Earth every year, and there has already been one near-catastrophe. In 1908, the Tunguska meteor-airburst over Siberia fortunately affected a largely unpopulated wilderness, but while it did kill only three people, and some reindeer, it flattened 2150 km^2 of Taiga forest (*Wikipedia and other sources*). Most workers estimate the meteor's diameter to have been over 50 m, possibly as much as 200 m (*Olga Gertcyk: Siberian Times, April 2020*), and although it only skimmed the Earth the resulting explosive strength of 12 megatons was 1000 times more powerful than the Hiroshima bomb. Had it followed a slightly different course it could have destroyed a whole city, and more. That it did not was down to pure luck, but archaeologists have found two instances in the recent past where humanity was not so lucky.

… destruction at the YDB event

The first example is geologically significant as it forms part of the on-going Younger Dryas Boundary Event (YDB) controversy, which revolves around the possible extra-terrestrial cause of a dramatic global climatic cooling event, reviewed in *Geobrowser* for 2018. In 1972–73, an archaeological site was excavated at the prehistoric mound-settlement of Abu Hureyra, by the side of the Euphrates River in Syria, just before the area was flooded by damming to form Lake Assad. Revisiting the material excavated from the site, a team headed by Moore and Kennett (*2020: www.nature.com/scientificreports*) studied material from a charcoal-rich living surface that returned a YDB age of 12,825 ± 55 cal BP (range: 12,935–12,705).

In the same layer were peak abundances of meltglass, nanodiamonds and microspherules, together with high concentrations of iridium, platinum, nickel, and cobalt: all features typical of a cosmic strike. Meltglass temperatures estimated to range between 1720°C and 2200°C rule out formation due to thatched

hut fires, while the low values of remanent magnetism indicate that the meltglass was not caused by lightning. There is no crater, so the researchers concluded that Abu Hureyra and its inhabitants, as well as much of the surrounding Euphrates floodplain, were destroyed by a meteor airburst. The disaster is mirrored by findings at YDB archaeological sites spanning four continents, all featuring high-temperature meltglass, melted microspherules, and high platinum-iridium concentrations. The global nature of these events was attributed to the planet's passage through a million kilometres-wide cometary debris cluster.



Typical example of Abu Hureyra meltglass. Upper image is a photomicrograph of a 7.8-mm glass fragment from the devastation layer. Lower image is a SEM view of the same glass fragment (Source: Moore, Kennett et al., 2020)

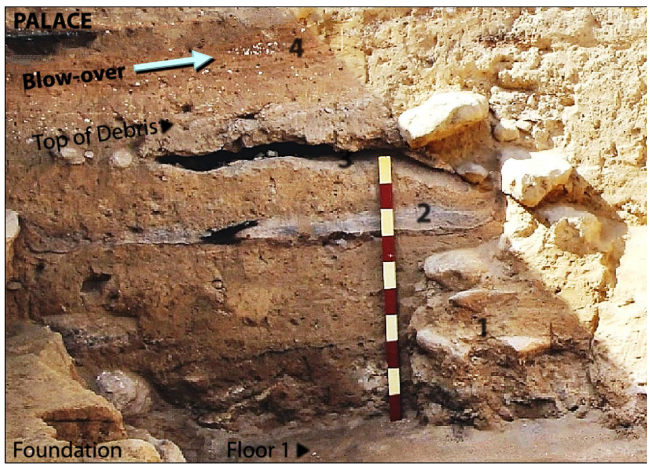
… and Sodom revisited

This second example refers to much more recent devastation involving the loss of human life on a biblical scale. Chapter 19 of the Book of Genesis (Authorised Version) explains the destruction of Sodom and Gomorrah as the Lord's retribution served on the allegedly iniquitous behaviour of the inhabitants. But the findings of a study by a multidisciplinary team point to this being the world's only truly historical record of a thriving populace destroyed by an exploding extra-terrestrial body (*Bunch et al., 2021, Nature Scientific Reports*: *doi.org/10.1038/s41598-021-97778-3*). The focus here is the location of Sodom, which has long been regarded by archaeologists and Bible scholars alike as the ruins of a Middle-Bronze Age city in the Jordan valley close to the north-eastern shore of the Dead Sea.

A major feature of the Tall el-Hammam ruins is a ~1.5 m-thick, city-wide ashy 'devastation layer', in which the researchers found peak concentrations of shocked quartz, melted pottery, mudbrick fragments, diamond-like carbon, soot, Fe- and Si-rich spherules and $CaCO_3$ spherules from melted plaster. Melted platinum, iridium, nickel, gold, silver, zircon, chromite and quartz were also recorded, with heating experiments indicating temperatures exceeding 2000 degrees centigrade. Shattered human bones excavated from the devastation layer "*…suggest that at the moment of death, these individuals were going about normal activities inside the palace, on the upper ring road, and/or on the rampart above the road, where they were struck by a high-temperature thermal pulse, followed by a hyper-velocity blast wave from a catastrophic cosmic airburst*." The researchers concluded that at Tall el-Hammam the shock wave was directed to the northeast, and its magnitude is consistent with the airburst of a 60–75 m-size meteor.

Between 4 and 54 weight per cent of salt was detected in the destruction layer, in contrast to the negligible amounts of salt in the layers above and below, suggesting that the airburst ripped up and redistributed high-salinity surface sediments and water from the Dead Sea area, substantially increasing surficial salinities both within the city and in the surrounding fields. This hurricane of salt-laden material appears to have been woven into the Bible's 'pillar of salt' myth behind the demise of Lot's unlucky wife (re-interpreting Genesis 19 vs 8 & 9, it seems probable that she was left behind in Sodom after an angry mob had forced Lot to flee). Anyone who survived the blast would have been unable to grow crops due to this excess salinity; in fact agriculture was inhibited to such an extent that some 120 settlements within a *c.* 25-km radius were abandoned for hundreds of years afterwards.

Radiocarbon dating by Bunch *et al.* shows that Tall el-Hammam's destruction occurred at around ~1650 BC. Given that most scholars concur that the Book of Genesis was probably first written down around 1445 to 1405 BC (*BibleGateway blog; February 2016*), there would have been plenty of scope time-wise to modify or embellish oral traditions recounting this disaster. There is admittedly some debate as to whether Tall el-Hammam was actually the location of Sodom (*e.g. The Times of Israel, September 2021*); however, the research team considered that the few details in Genesis were a



Devastation layer at Tall el Hammam's Palace, features labelled as follows.1: broken mudbricks and debris from shattered upper walls; 2 and 3 are voids and layers formed when trapped textiles (rugs and tapestries) burned, leaving only fibrous ash and carbon; 'Blow-over' layer (blue arrow) is composed of windblown, laminated destruction deposits that sealed the ruined structure for ~ 3600 years; 4 marks fragments of white limestone plaster, mixed with carbonate spherules, from the palace walls and ceiling. Scale stick has 10-cm markings (Source: Bunch et al., 2021)

'*reasonable match for the known details of a cosmic impact event'*. Certainly, a massive cosmic airburst is in keeping with the account in Genesis 19 vs 24 & 25 that it "*…rained upon Sodom and Gomorrah brimstone and fire…out of heaven*", which affected "*…all the plain and all the inhabitants…and that which grew upon the ground*". The reference to 'brimstone' here could just be an example of literary hyperbole, but it may also refer to accounts of noxious sulphurous gases released during the event. These could have originated from the incineration of sulphate minerals such as gypsum, found along with halite in modern Dead Sea evaporite deposits (*Garber et al., 1987: Carbonates Evaporites 2, doi.org/10.1007/BF03174303)*.

As a postscript, the radiocarbon evidence presented by the researchers indicates that, within error limits, the Tall el-Hammam event was coeval with the destruction of Jericho, 22 km to the west (*Joshua, 6: vs 1–27*). In that more distant location, they estimate that the shock wave would have had a velocity of about 140 mph: powerful enough to shear and collapse the predominantly mudbrick structures of that time.

This scientific explanation of a biblical story provides an additional justification for NASA's mission, but has predictably raised a storm of protest from religious quarters (*website: "Criticism engulfs paper claiming an asteroid destroyed Biblical Sodom and Gomorrah"*). The 21 co-authors have nevertheless meticulously researched their findings and are at pains to discuss, in some depth, possible alternative explanations for each one of the 24 lines of evidence presented.

World's largest in Northumberland

It's not every time that a geological field excursion turns up something really exciting, but that is what happened on a chilly Howick Beach in January 2018. Recent storms had caused rockfalls along cliffs exposing early Carboniferous (Pendleian) sandstones, and in the debris geologists from Cambridge University uncovered a partial fossil of the giant millipede, *Arthropleura.* But this was no ordinary specimen: according to the discoverers (*Davies et al.: doi.org/10.1144/jgs2021-115*), the original creature must have been about 55 cm wide and 2.63 m long, with a weight of about 50 kg, making it '*...one of the largest known arthropod fossils and the largest arthropleurid recovered to date*.'

In some respects this size estimate is not surprising, since it is well known that extremely large invertebrates, for example dragonflies the size of modern seagulls, and huge cockroaches infested the Carboniferous equatorial rainforest. The reason for this at first seemed obvious: so vast were the rainforests that they raised global atmospheric oxygen to levels of around 30 per cent, much higher than current levels of 21 per cent, and this might have aided the increased size of invertebrates. But against this it is also known that oxygen can be poisonous in large quantities, and some workers have suggested that in the Carboniferous, gigantism may have helped creatures to avert oxygen toxicity by absorbing lower percentages of the gas, relative to their body sizes. This selection process evidently began at times when oxygen levels were perhaps not much higher than current ones, but were rising dangerously.

75 cm-long segment of the Northumberland Arthropleura *(Source: Neil Davies)*

In discussing this with Sarah Collins (Cambridge University website, December 2021), Neil Davies noted that the Northumberland *Arthropleura* had attained its size about 326 million years ago – well before the Carboniferous oxygen maximum (at about 300 million years). Rather than atmospheric oxygen levels, he suggests that factors such as verdant vegetation and an abundance of prey, may have combined to make this millipede a particularly successful, well-fed apex predator – and size goes along with that.