GEOBROWSER

High-tech element from Cornwall

The UK Government's ruling that from 2035 no new cars are to be powered by fossil fuels will add considerable impetus to the scramble for viable forms of alternative energy storage. At present the main contender is the rechargeable lithium-ion battery, which has some drawbacks safety-wise but is already widely used for the current generation of electric vehicles. Lithium will also be used for the new-generation solid-state batteries being developed, which have the potential to extend driving distance while cutting charging time by two thirds (*NikkeiAsia website, December 2020*).

Not surprisingly therefore, the government has prioritised lithium as a 'metal of importance' within the technology sector. In fact, estimates are that by 2035 the UK's annual demand will be 75,502 tonnes (of battery-grade lithium carbonate equivalent), up from only 2200 tonnes in 2020 (*The Times, 3 June 2021*). At present just about all of the world's lithium is mined from lake brines in Argentina, Chile, Bolivia and China, or from large open-cast operations in Australia, where it is extracted from the pyroxene-mineral spodumene (see also Alan Filmer's report, p 78, this issue). There are also reports of potentially vast lithium reserves in the dried-up salt-lake basins of Afghanistan (*Mining.com; 16 June 2010*), which China will no doubt be in pole position to exploit following the West's hurried exit from that country in August this year. In 2020, China was already processing 80 per cent of the world's battery grade lithium (*Benchmark Mineral Intelligence, 6 May 2020*), but the UK could go some way to achieving its own self-sufficiency thanks to two radically different types of lithium resource under investigation in Cornwall.

Lithium from Cornish hard-rock

The most conventional operations to extract lithium will involve open-cast mining at former China clay pits near St Austell. At one site, on-going exploration by British Lithium has revealed over 200 m of mineralisation, continuous from the surface. The lithium is held in the mica known as zinnwaldite, and the low-energy method for its extraction from this mineral is being touted as a highly innovative 'world-first'. In a web-posting for 2020, the company said it is upgrading its metallurgical laboratory in Cornwall to include beneficiation, pyro-metallurgical and hydro-metallurgical equipment — a first of its kind in the UK. If the metallurgical research is successful, the company estimates that the planned quarry and processing plant could produce about 20,000 tonnes of lithium a year, as well as providing 3000 jobs (*Cornish Stuff website; Sep 2019)*. In a separate hard-rock mining venture, which also targets former china clay quarries, a second company, Cornish Lithium, have estimated a lesser but still significant annual potential target of 10,000 tonnes (*The Times, 3 June 2021*).

… and from Cornish water?

A totally different lithium resource, also centred in Cornwall's historic mining area, comprises reserves that have been found in geothermal waters intersected by drilling at depths of between 600 m and 5.2 km. It is being pioneered by Cornish Lithium, who are focussing prospection on the circulating geothermal brine systems that occur naturally beneath the surface in and around Cornish granites (*Cornish Stuff; September, 2020)*. The finding is not new: the lithium content of these springs was a feature of great scientific interest as far back as 1864, during the hey-day of Cornwall's mining history.

Cornish Lithium has announced very high average lithium concentrations of 220 mg/l, with the added bonus that, relative to other geothermal waters in the world, concentrations of total dissolved solids are low, and there are 'ultra-low' amounts of magnesium — factors that will considerably reduce the cost of processing. The potential by-products include boron, rubidium, caesium, potassium and, of course, the geothermal energy itself which will be used to power the various extraction and processing operations.

Operations are currently centred on the newly-developed United Downs Geothermal Power site, operated by Geotherm Ex at a location close to Redruth. Drilling there has intersected waters heated at 190 degrees Celsius in the vicinity of the Porthtowan Fault Zone. The pilot £4 million extraction plant will be part-funded by the UK Government and will trial direct lithium extraction (DLE) technology, which removes dissolved lithium compounds from water without the need for the large evaporation ponds. Although lithium from Chile and Argentina is of higher grade than geothermal sources, there are concerns over the sustainability of those operations.

Exploration borehole site for geothermal lithium extraction (Image courtesy of Cornish Lithium)

Cornish Lithium expects commercial production to begin in three to five years, but note that there are already four more potential prospects, and as many as 20 other promising geothermal sites, in Cornwall. Although the potential annual lithium output from these Cornish waters has not yet been fully evaluated, compared to hard-rock quarrying the extraction of water-based lithium is a relatively simple, cheap and environmentally friendly operation. So much so that geothermal investigations by other companies are being rolled out nationwide, one target being the buried or partially buried Ordovician granodiorite plutons found in and around Leicestershire.

Winchcombe meteorite—carbon special

On 28 February this year, a meteorite landed in the village of Winchcombe, Gloucestershire. The event was widely reported as it is both dramatic and fairly unusual for the UK, where only several such landings have occurred since the large stony meteorite that hit Barwell, near Leicester, on Christmas Eve 1965. The Winchcombe meteorite is particularly important, however, because it has been identified as a carbonaceous chondrite — an extremely rare variety of meteorite and the first of its type to have fallen in the UK. In the global perspective, of the 65,000 meteorites recorded around the world only about 1,000 were carbonaceous chondrites (*Josh Davis, Natural History Museum website, 14 May 2021*).

These fall into eight groupings, but most will typically contain spherical chondrules of olivine and pyroxene surrounded by a feldspathic matrix that may either be glassy or crystalline. At the time of writing, the outline composition of the Winchcombe meteorite has been determined from studying the 535 grams-heavy type sample. A powder XRD analysis shows it contains Fe-Mg serpentinites, tochilinite (a complex hydroxysulphide mineral), olivine, calcite and magnetite (*Meteoritical Bulletin Database, 24 July 2021*). The analysis confirms that the meteorite contains organic material, and places it within the CM2 grouping of carbonaceous chondrites. This is highly significant because other CM2 meteorites, such as the Murray (USA) meteorite, which fell in 1950, contain amino acids (*R. Verish, Meteorite Times Magazine, July 2019*). Other examples contain nucleic acids (RNA and DNA) and also purines, the latter being chemical compounds associated with the construction of those molecules (*Callahan et al., 2011: doi 10.1073/pnas.1106493108*). Moreover, sugar molecules such as ribose, have been detected in carbonaceous meteorites (*Steigerwald et al., Astrobiology, Nov 2019*), supporting earlier suggestions that chemical processes on asteroids can produce some of the bio-ingredients essential to life.

It is understood that carbon, together with oxygen and many other elements, could only have been synthesised by nuclear reactions in the interstellar medium *(CMo'D Alexander, Encyclopaedia Britannica, 2007)*, probably around stars at or near the end of their lives (see also *Geobrowser* for 2020). It is therefore believable that under the right interstellar conditions, these elements will combine to form the organic molecules observed inside carbonaceous chondrites. These compounds do not in themselves constitute life, but their very presence does raise the intriguing question of how life could have originated, and here there appear to be two opposing arguments. Exogenous theories hold that (albeit primitive) extra-terrestrial life-forms journeyed to our planet on meteorites, but the alternative view is that life developed endogenously — purely by biochemical processes initiated in Earthly environment(s).

Sample of the Winchcombe meteorite (Image courtesy of the Trustees of the Natural History Museum)

Could 'life' have arrived on meteorites?

The exogenous notion, that some carbonaceous meteorites may have hosted viable microscopic life-forms, as opposed to just organic molecules, has been rigorously pursued through the various hypotheses that shelter under the umbrella of 'Panspermia'. This contends that simple organisms, such as spores or bacteria, can survive existence in space and are thus constantly available to colonise new worlds. The thorough treatise in *Wikipedia* notes that this is by no means a modern concept, having been first touched on in the 5th century BC by the Greek philosopher, Anaxagoras. More recently it was given some degree of respectability through the authorship of Hoyle and Wickramasinghe, who suggested that extra-terrestrial life-forms delivered directly to the Earth could be responsible for certain plagues and pandemics (*Hoyle et al. 1979, Viruses from Space and Related Matters, University College Cardiff Press*). It should be noted that no living or even fossilised organisms have yet been unequivocally demonstrated in meteorites. In 1996 researchers claimed to have found microscopic bacteria in the Allan Hills 84001 Martian meteorite, but their findings continue to be regarded as highly controversial by others: for example, Meghan Bartels in the *Newsweek* website for 6 July 2021 *('How does life start?')*.

Of the several mechanisms proposed for Panspermia, the most far-fetched invoke the actions of alien intelligences (Directed panspermia). More testable is the rather more rigorously scientific although nonetheless speculative theory of 'lithopanspermia', whereby actual organisms are transferred from rocks ejected from a planet such as Mars, or even from a planetesimal (see below), before finally ending up on Earth. The idea has even been evaluated by experimentation, albeit of rather short duration, utilising space rockets and orbital vehicles. Emerging from this is the suggestion that some simple extremophile organisms, if locked into meteors, or existing as 'space dust', might be capable of surviving the threefold stages of planetary ejection, transit and atmospheric entry. To this must be added a fourth stage, which we may call 'survival and proliferation', whereby life emerges from a shattered meteorite into an Earthly environment that just happens to be so perfect that it can immediately adapt, and then flourish. There is much scepticism about this, and many scientists argue that while it is self-evident that organic *molecules* do arrive on meteorites, 'life' itself is unlikely to survive such an ordeal (*von Hegner, 2020: Interplanetary transmissions of life in an evolutionary context, International Journal Astrobiology, 19, 335–48*).

Illustration of the lithopanspermia theory of life on Earth. A comet or asteroid strikes a planet, in this case Mars, which then ejects biologically-rich matter into space, eventually settling on Earth (Image courtesy of Tobias Roetsch/Future Publishing via Getty Images)

… or was life created here on Earth?

In opposition to Panspermia is the possibility of a more indirect, endogenous link, whereby extra-terrestrial carbonaceous material, introduced during the fiery birth of our Solar System about 4.6 billion years ago, became a resource for synthesising new organic compounds once the Earth had stabilised. A recent study suggests that after delivery to our embryonic solar system, interstellar carbon was first of all processed into planetesimals (small planetary precursors), which retained significant amounts of the element in organic molecules; it is their relics which we now see as the carbonaceous chondrites. The planetesimals then accreted to form the Earth and in that process it seems that carbon was lost, perhaps explaining why the silicates making up the crust and mantle of the Earth have a carbon concentration that is five to ten times less than in carbonaceous chondrites (*Li et al., 2021; doi: 10.1126/sciadv.abd3632*). Migration of elemental carbon into the Earth's core may have accompanied some of the carbon loss (*Li et al., 2019; doi:10.1017/9781108677950.011.*).

This accretionary phase of the Earth's development would presumably have dissociated any originally introduced organic material, in which case the subsequent release of carbon and other elements, such as hydrogen and oxygen, to sites where organic molecules could once again be re-formulated would have required the sort of stability offered by the newly consolidated Earth, with its three-layered configuration of core, mantle and crust. The availability of water has always been important to life, and it is envisaged that by the end of the last major meteor bombardment, about 3.8 billion years ago, the planet had cooled and stabilised sufficiently to allow oceans to develop, following millions of years of rainfall (*e.g. U.S. National Ocean Service website: 04/09/21*).

There is indeed tantalising evidence that very early in the Archaean, bacterial life-forms had evolved following what must have been a long period of chemical evolution of oceanic water. Thus the world's oldest and least controversial stromatolites, found at Strelley Pool in the Pilbara region of Australia and dated at about 3.5 billion years old, are indicative of cyanobacterial activity in shallow waters (*D. Wacey, Astrobiology, May 2010; doi: 10.1089/ast.2009.0423*). Another environment suggested to have been the 'crucible for life' is found along mid-ocean ridge systems, where gases such as methane and hydrogen, together with various organic compounds, originating within the core and mantle are expelled from hydrothermal vents such as black smokers or lower-temperature 'Atlantis'-type carbonate towers (*Konn et al., Astrobiology, May 2015; doi: 10.1089/ast.2014.1198*). It seems possible that in the cooler parts of these vents the ingredients for organic synthesis could have been assembled, which in time generated

Strelley Pool stromatolite (Image courtesy of Fossil Mall) simple amino acids in concentrations that would favour the development of self-replicating peptides, RNA and DNA, and ultimately the emergence of primitive life (*Russell & Hall; 1997, Journal Geological Society: doi.org/10.1144/gsjgs.154.3.0377*).

The endogenous theory was first tested in the laboratory by the Miller–Urey experiment, performed in 1952. This simulated the conditions thought at the time to be present on the early Earth, and tested the chemical origin of life under those conditions (*Miller, 1953, Production of amino acids under possible primitive Earth conditions, Science, v.117*). The experiment supported earlier hypotheses that conditions on the primitive Earth could have promoted the synthesis of amino acids from basic inorganic precursors. It stimulated many subsequent experiments, and work is still on-going to replicate simple life-forms from molecules such as amino acids (*e.g. Las Cumbres Observatory website: How did life start on Earth?*). None of these experiments has succeeded in synthesising life, but then they are inevitably of short duration. In contrast, modern mid-ocean ridge vent systems have active life-spans of up to at least 30,000 years (*Kelley et al., 2005, Oceanography, v.18*). Long enough, perhaps, for the synthesis of simple life-forms, which could then evolve, adapt and populate the wider oceanic environment?

This raises the possibility that the start of life on Earth could be inextricably linked to the onset of plate tectonics. The most reliable evidence for that process are ophiolite complexes, which when fully developed signify the presence of oceanic crust. One timeline for this is the world's oldest ophiolite, found in the Isua greenstone belt in Greenland, which has been radiometrically dated to 3.8 billion years (*H. Furnes et al., Science, Mar 2017: doi:10.1126/science.1139170*). Thus over a few hundred millions of years of protracted natural 'experimentation', some forms of bacterial life could have adapted sufficiently to enable their migration out of the oceanic hydrothermal 'crucible', and into the shorelines of the newly created continents.

Deformed oceanic pillow lava in the Isua Greenstone Belt (Image courtesy of Alchetron)

REPORT

Australian lithium minerals

In view of the present interest in lithium minerals, it was a pleasant surprise to find a large quarried boulder containing spodumene and lepidolite in a garden outside the community centre in Hopetoun on the south coast of Western Australia. As is often the way with mining communities it sees regular cycles of boom and bust. Originally gold was the sought-after product. More recently nickel, but currently lithium. World demand for lithium, for battery use, is set to triple by 2025 (see Geobrowser, this issue).

Large crystals of spodumene within a matrix containing small flakes of lepidolite mica; boulder about 80 cm across.

Lepidolite, showing characteristic micaceous or flaky habit.

Spodumene, a member of the pyroxene family, is a lithium aluminium silicate ($LiAlSi_2O_6$) and an important ore of lithium. Lepidolite is a lithium-bearing mica and occurs with spodumene in a pegmatite body overlying granite (tonalite) on Mount Cattlin, just north of Hopetoun. The Mount Cattlin open-pit mine extracts spodumene-tantalite from a pegmatite ore reserve currently grading 1.04% Li_2O and 139 ppm Ta_2O_5. After removal of the overburden the near horizontal pegmatite is stripped off and processed on site to produce a spodumene concentrate and tantalite. This is all shipped to China from the port of Esperance. The mine cannot be visited.

Alan Filmer