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RAW MATERIALS FOR DECARBONISATION

The potential for lithium in the UK

MAY 2020

Introduction

Lithium is a soft, silvery-white to grey alkali metal with a metallic lustre when fresh. It is highly reactive and in air quickly tarnishes to a dull silvery-grey and then black. Its physical and chemical properties make it useful in many chemical and metallurgical applications, for example lubricating greases, ceramics and glass, aluminium production and batteries. In the UK lithium is primarily used in the manufacture of lithium-ion batteries. The UK imports lithium in several forms, which include lithium carbonate, lithium oxide and lithium hydroxide. In 2017 the UK imported 1919 tonnes of lithium carbonate and a combined 324 tonnes of lithium oxide and hydroxide (Bide et al., 2019).

In 2017 nine countries were known to be producing lithium, amounting to almost 58 000 tonnes of contained lithium. Of these, five countries are producing lithium minerals (Australia, China, Zimbabwe, Portugal and Brazil), while four are extracting lithium from brines (Chile, Argentina, China and USA) (Brown et al., 2019). Between 1993 and 2017 global mine production of lithium increased at a compound annual growth rate of almost nine per cent. Production is dominated by Australia, which accounted for 54 per cent of the total in 2017. Other significant producers include Chile (26%) and Argentina (9%).

This profile provides an overview of the geological potential for lithium in the UK. It forms part of a series on raw materials used in decarbonisation technologies that may occur in the UK, and is based on publically available data and information.

Lithium is found in economic concentrations in two main types of mineral deposit: minerals and brines. In terms of minerals, lithium is primarily extracted from lithium aluminosilicates, for example spodumene ($LiAlSi_2O_6$), petalite ($LiAlSi_4O_{10}$) and eucryptite ($LiAlSiO_4$), which are found in pegmatite deposits. However, hectorite ($Na_{0.3}(Mg,Li)_3Si_4O_{10}(OH)_2$), a lithium-rich smectite clay mineral, and jadarite ($LiNaSiB_3O_7(OH)$), a lithium-bearing borosilicate mineral, may be important sources of lithium in the future. Lithium extraction from brines is chiefly from continental brine deposits, such as the salt lakes and salt pans of the central Andes in South America. The extraction of lithium from geothermal and oilfield brines is also technically feasible and may become another important source of lithium in the future (Brown et al., 2016).

UK production and resources

In the UK lithium primarily occurs as a minor element in the mica found in granite and granite pegmatites, especially in south-west England. In fact lithium-bearing mica was first identified in the St Austell Granite in south-west England in 1825. During the 19th century a small amount of lithium-bearing mica was extracted from the Trelavour Downs pegmatite within the St Austell Granite, for use in firework manufacturing (Hawkes et al., 1987). This working is the only known site of lithium extraction in the UK. Other lithium minerals, such as amblygonite ($(Li,Na)AlPO_4(F,OH)$), spodumene, petalite, montebrasite ($LiAl(PO_4)(OH, F)$) and elbaite ($Na(Li_{1.5}Al_{1.5})Al_6Si_6O_{18}(BO_3)_3(OH)_4$), are very rare and have only been documented at a few localities in the UK (Tindle, 2008). There is currently no mine production of lithium in the UK and there are no deposits in which lithium reserves or resources have been reported.

To date there has only been limited evaluation of the lithium potential in the UK. During the 1980s the BGS undertook an assessment of the potential to recover lithium from mica in the St Austell Granite in south-west England (Hawkes et al., 1987). Since 2017 two exploration companies, Cornish Lithium Ltd and British Lithium Limited, have started exploring for lithium in south-west England. Furthermore the Li4UK project has recently (August 2019) undertaken systematic lithogeochemical sampling at various sites across the UK, with the aim of evaluating domestic lithium resources (Li4UK, 2019). However, to date (May 2020) no public domain data have been reported by Cornish Lithium, British Lithium nor the Li4UK project.

UK occurrences

South-west England

All of the major granite bodies in south-west England contain lithium-bearing micas, although the amount of lithium contained in the micas is highly variable. For example, biotite from the Carnmenellis Granite contains up to 3450 ppm Li, whereas maximum values in muscovite from the Land's End Granite are somewhat higher at 4431 ppm. The lithium content of true lithium micas, such as zinnwaldite ($KLiFeAl(AlSi_3)O_{10}(OH,F)_2$) and lepidolite ($K(Li,Al)_3(Si,Al)_4O_{10}(F,OH)_2$), is much higher. For example, zinnwaldite from the St Austell Granite contains up to 17 818 ppm Li, while lepidolite from the same granite body can contain up to 23 953 ppm Li (Simons et al., 2017). There are three granite bodies in south-west England that are known to contain appreciable amounts of zinnwaldite and lepidolite, namely the Tregonning-Godolphin and St Austell Granites, and the Meldon Aplite.

The bulk lithium content of the Tregonning-Godolphin Granite was assessed during the 1980s by Hawkes and Dangerfield (1986). They found the lithium concentration in biotite-granite from Godolphin Hill to be lower (average 163 ppm) than the concentration observed in lithium-mica-bearing granite from Tregonning Hill (average 1315 ppm). They also found that areas of the Tregonning-Godolphin Granite that had been affected by hydrothermal activity had the lowest lithium concentration (average 50 ppm); they attributed this to the breakdown of primary magmatic micas and the subsequent loss of lithium. The estimated area of outcrop of biotite- and lithium-mica granite, are four km^2 and eight km^2, respectively. However, at that time no formal assessment was made of the lithium resource contained in the Tregonning-Godolphin Granite for two reasons: (1) the area is designated an area of outstanding natural beauty; and (2) the St Austell Granite was deemed to be a geologically, technologically and economically more attractive target (Hawkes et al., 1987). The lithium phosphate amblygonite has also been identified in the Tregonning-Godolphin Granite; however, it is a minor phase with a modal abundance of up to

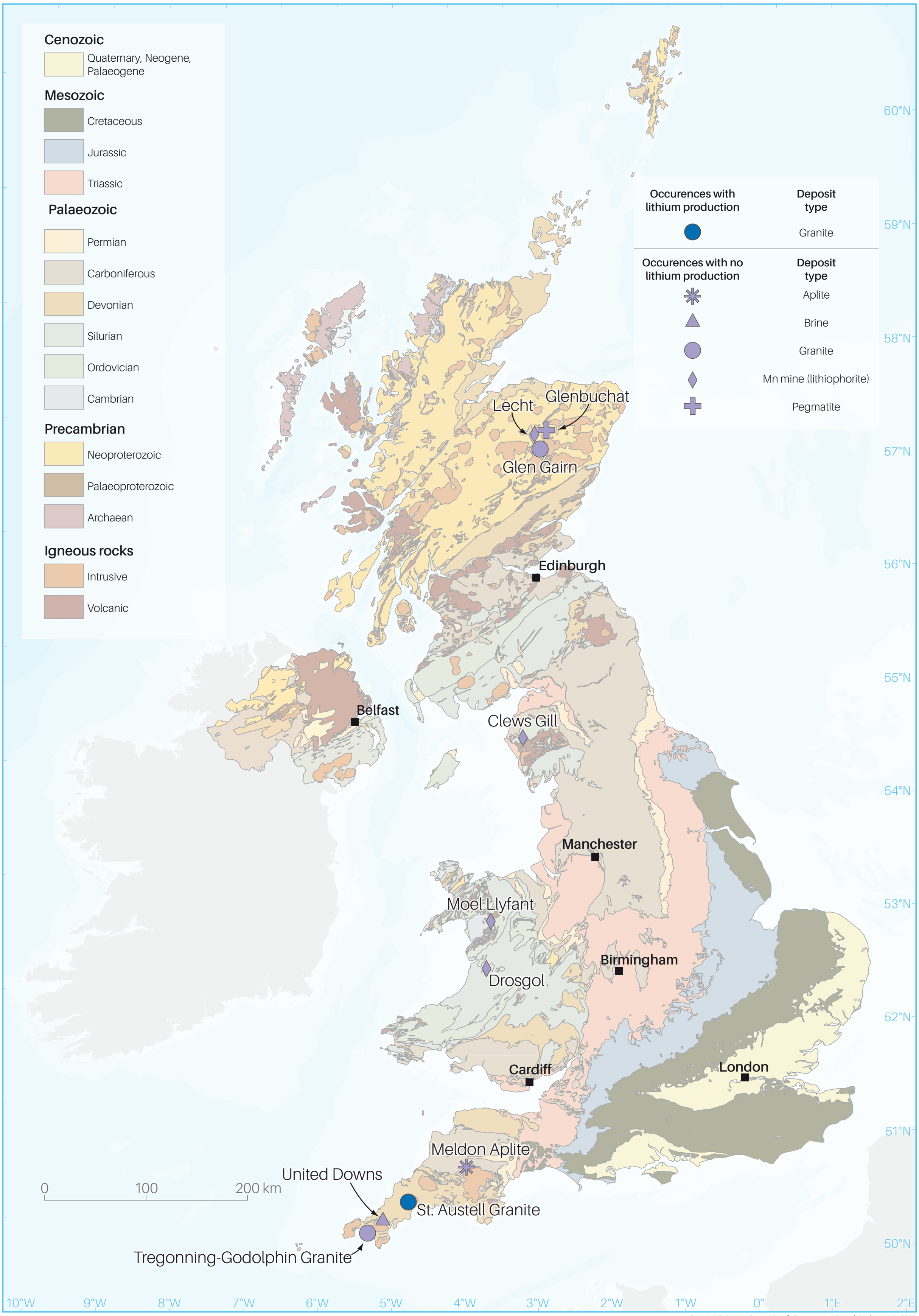

Figure 1 Location of principal lithium occurrences in the United Kingdom.

1.7 per cent (Stone and George, 1978). Zinnwaldite, amblygonite, triphylite ($LiFe^{2+}PO_4$) and lithiophylite ($LiMnPO_4$), have also been identified in the aplite-pegmatite dykes at Megiliggar Rocks, near Rinsey on the south Cornish coast. These gently-dipping intrusions are considered to be highly-evolved melts that are genetically-related to the Tregonning-Godolphin Granite (Breiter et al., 2018; Stone and George, 1985).

The St Austell Granite is a composite granite body with an outcrop area of approximately 92.5 km^2. It comprises three distinct rock types: (1) coarse-grained biotite granite; (2) fine-grained biotite granite; and (3) medium-grained lithium-mica granite. The lithium-mica granite has an outcrop area of about 8.5 km^2 and contains approximately nine per cent lithium-mica. The highest bulk-rock lithium values correlate with the outcrop of lithium-mica granite (i.e. the Nanpean District and Hensbarrow Beacon) (Hawkes et al., 1987). Biotite-granites adjacent to the lithium-mica granites are also enriched in lithium, which led Dangerfield et al. (1980) to conclude that the biotite-granites may be underlain by lithium-mica granite. Hawkes et al. (1987) suggested that where biotite-granites contain upwards of 600 ppm Li the contact with the lithium-mica granite may be as shallow as 50 to 100 m below surface. An assessment of the lithium potential of the St Austell Granite was made by Hawkes et al. (1987), based on a 100 m thick slab across the four grade zones observed in the pluton. The resource estimate for the entire pluton (92.5 km^2) is in the region of 16 million tonnes of lithium. However, only areas of lithium-mica granite would yield ore-grade rock, which equates to an area of about eight km^2 or a tonnage of about 3.3 million tonnes of lithium (Table 1).

Mineralogical studies showed that nearly all of the lithium is contained in mica, with a range of lithium concentrations from 0.5 wt. % up to 2.5 wt. %. Theoretically a large proportion of this mica could be extracted as a by-product of china clay extraction operations in the lithium-mica granites. Waste rock containing lithium-mica could be crushed and milled. Subsequent flotation of the milled material could yield a 2 wt. % Li-concentrate (Hawkes et al., 1987).

Historically material extracted from the Meldon Aplite, located in Okehampton, Devon, was primarily used to manufacture glass and ceramics. Although lithium was never commercially extracted from the aplite the presence of lithium at Meldon has been known for over 100 years. It was Waller (1889) who first determined lithium in samples from Meldon, reporting a whole-rock value of 0.7 wt. % Li_2O. A large number of mineral species have been identified in the aplite, including the following lithium-bearing phases: elbaite tourmaline, petalite, amblygonite, montebrasite and lithium-mica (lepidolite) (Chaudhry and Mahmood, 1979; von Knorring and Condliffe, 1984). The body is steeply-dipping (50°) and has a strike length of about 3.3 km and a thickness of about 15 m (Hawkes et al., 1987; Worth, 1920). Hawkes et al. (1987) determined the average lithium content of the Meldon Aplite to be about 3000 ppm, although values of up to about 7000 ppm were also observed. Based on its thickness, strike length and average lithium content, Hawkes et

Table 1 Regional resource estimate for the St Austell Granite (Hawkes et al., 1987).

Grade zone (ppm Li)	Area (km^2)	Estimated Li content for a 100 m thick slab (tonnes)
<600	66.0	8 000 000
600–1200	18.5	4 500 000
1200–1800	7.0	2 800 000
>1800	1.0	490 000
Total	92.5	15 790 000

al. (1987) estimated the Meldon Aplite to contain approximately 45 400 tonnes of lithium. However, there are a number of reasons cited by Hawkes et al. (1987) as to why the Meldon Aplite is unlikely to be a commercial source of lithium, including: (1) the narrowness of the body and steep-dip; (2) the low average lithium grade; and (3) the close proximity of the dyke to the Dartmoor National Park.

There are currently two companies actively exploring for lithium in south-west England, one is focussed on lithium extraction from geothermal brines (Cornish Lithium Ltd, 2019), whilst the other is investigating lithium-bearing mica in the St Austell area (British Lithium Limited, 2019).

North-east Scotland

An occurrence of gem-quality elbaite (Li-tourmaline) is known at Glenbuchat, near Ballater, in north-east Scotland. The gem-tourmalines are found in a series of pegmatitic float boulders that cover an area approximately 200 m long by 50 m wide. It is the occurrence of these elbaite-bearing boulders that has led some workers (Jackson, 1982; Starkey and McMullen, 2017) to suggest there may be a buried LCT (lithium-caesium-tantalum) pegmatite at depth; however, this has never been fully substantiated. Lithium minerals identified in the float material at Glenbuchat include: lepidolite, spodumene and elbaite (Starkey and McMullen, 2017). Whole-rock lithium concentrations up to 1.7 wt. % have been reported in lepidolite-rich samples (Shaw and Goodenough, 2013). LCT pegmatites typically occur in 'swarms' of multiple intrusions, so it is considered unlikely that the Glenbuchat occurrence is an isolated one.

Located about 30 km south-west of Glenbuchat, at Gairnshiel Lodge, is the Glen Gairn Granite (ca. 40 km^2). The eastern part of this body is known as the Coilacreich Granite (ca. 20 km^2), in which lithium-bearing mica is known to occur. Associated with the Coilacreich Granite is a much smaller (ca. 1 km^2) body of zinnwaldite granite, in which zinnwaldite comprises between 5 and 20 per cent of the rock, although no other lithium minerals have been reported from this locality (Hall and Walsh, 1972; Smith et al., 2002). Unusual tungsten-tin-molybdenum-bismuth-silver mineralisation, known to be associated with hydrothermally altered parts of the Coilacreich Granite, has been studied in detail by Tindle et al. (1987), Tindle and Webb (1989), and Webb et al. (1992). However, no systematic evaluation of the lithium potential of the Coilacreich Granite has been undertaken.

Other lithium occurrences

Lithiophorite ($(Al,Li)Mn^{4+}O_2(OH)_2$), a lithium-bearing secondary manganese mineral commonly found in the oxidised parts of hydrothermal ore deposits and sedimentary manganese deposits, has been reported at several localities in the UK, including: the Lecht manganese deposit in north-east Scotland (Wilson et al., 1970); the Drosgol manganese mine in mid-Wales (National Museum Wales, 2011); and the historic haematite workings at Clews Gill in Cumbria (Clark, 1963). Lithiophorite from these localities is typically blue-black and occurs as massive, fine-grained aggregates or as botryoidal masses up to a few centimetres across.

Resource potential

Even though lithium minerals are known to occur in the UK, many of them, with the exception of lithium-bearing micas, are very rare and are found only in minor amounts at a few localities. It is worth noting that lithium has never been commercially extracted in the UK, with the exception of a minor amount of small-scale working for a local market at the Trelavour Downs pegmatite in south-west England during the 19th century. Systematic exploration for lithium in the UK has been extremely limited, although in the past two years (2018–2019) there has been a significant increase in research and commercial exploration for lithium. This is most notable in south-west England, where ongoing exploration aims to sample geothermal waters to measure their lithium content. This will provide new data that is necessary to assess the resource potential and the feasibility of commercial extraction. Until a mineral resource estimate and the results of metallurgical testing of samples are published there is also uncertainly about the resource potential of hard rock lithium deposits in south-west England.

A priority target for further investigation is the buried spodumene-bearing pegmatite at Glenbuchat in north-east Scotland. The minerals present in the Glenbuchat pegmatite (i.e. spodumene, lepidolite, manganotantalite, manganocolumbite and elbaite)

(Starkey and McMullen, 2017; Tindle, 2008), and its extreme enrichment in rubidium, lithium, caesium, and tantalum (Shaw and Goodenough, 2013), are indicative of a highly-evolved LCT (lithium-caesium-tantalum) pegmatite. The known enrichment of lithium in similar LCT pegmatites elsewhere in the world provides a strong basis for evaluating this site further. The other target worthy of further investigation is the lithium-mica-bearing areas of the St Austell Granite. In 1987 Hawkes et al. estimated there to be about 3.3 million tonnes of contained lithium in the St Austell Granite; however, this figure could be higher as the estimate was based on an 'assumed' deposit thickness of 100 m.

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