UK Critical Minerals Intelligence Centre

MINERALS FOR THE UK'S NET ZERO TRANSITION

The potential for lithium in the UK

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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. The UK imports lithium in several forms, which include lithium carbonate, lithium oxide and lithium hydroxide. In 2020 the UK imported 1508 tonnes of lithium carbonate and a combined 467 tonnes of lithium oxide and lithium hydroxide (Bide et al., 2022).

In 2020 nine countries were known to be producing lithium, amounting to almost 86 000 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) (Idoine et al., 2022). Between 2000 and 2020 global mine production of lithium increased at a compound annual growth rate of 24 per cent. Production is dominated by Australia,

This profile provides an overview of the geological potential for lithium in the UK. It forms part of a series on the minerals the UK requires to transition its economy in the coming decades to net-zero emissions. It was produced by the British Geological Survey for the Department for Business, Energy and Industrial Strategy as part of the UK Critical Minerals Intelligence Centre.

British Geological Survey

which accounted for 48 per cent of the total in 2020. Other significant producers include Chile (27 per cent) and Argentina (seven per cent).

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, petalite and eucryptite, which are found in pegmatite deposits. However, hectorite, a lithium-rich smectite clay mineral, and jadarite, 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 mineral occurrences, exploration and production

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 nineteenth 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 historical lithium extraction in the UK. Other lithium minerals, such as amblygonite, spodumene, petalite, montebrasite and elbaite, are very rare and have only been documented at a few localities in the UK (Tindle, 2008). There is currently no commercial scale mine production of lithium in the UK, and only one deposit for which a lithium resource estimate that is compliant with international reporting standards has been publicly reported.

During the 1980s the British Geological Survey 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 Ltd, have started exploring for lithium in south-west England. A third company, Northern Lithium Ltd, have commenced lithium exploration in north-east England. Furthermore, the Innovate UK-funded Li4UK project has undertaken systematic lithogeochemical sampling at various sites across the UK, with the aim of evaluating domestic lithium resources (Li4UK, 2019). However, to date (August 2022) no public domain data have been released by Northern Lithium Ltd, British Lithium Ltd, nor the Li4UK project.

South-west England

All 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 mica from the Carnmenellis Granite contains up to 3450 parts per million (ppm) Li, whereas maximum values in muscovite mica from the Land's End Granite are somewhat higher at 4431 ppm. The lithium content of true lithium micas, such as zinnwaldite and lepidolite, 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

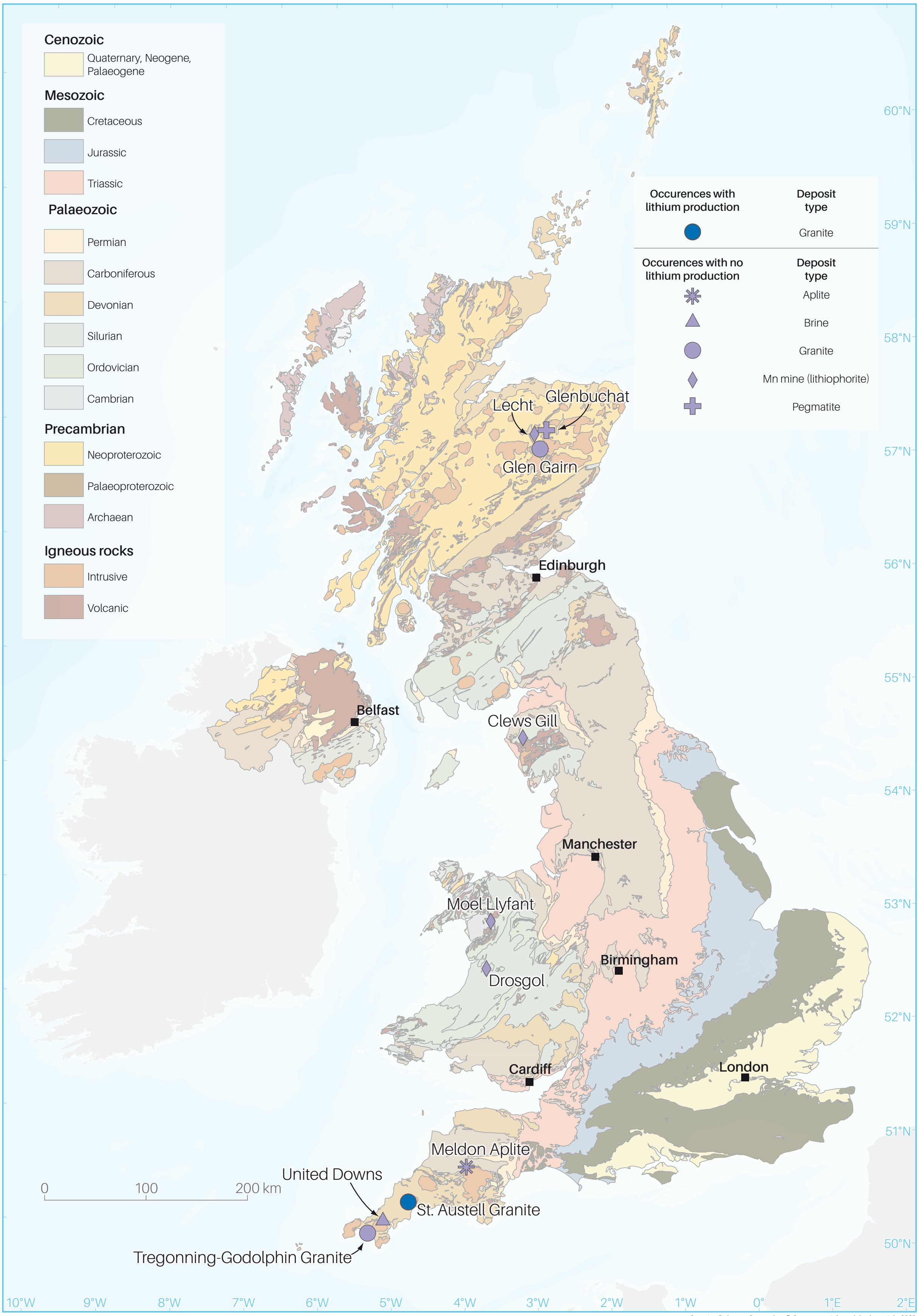

Figure 1 Location of the principal lithium occurrences in the United Kingdom.

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 mineral amblygonite has also been identified in the Tregonning-Godolphin Granite; however, it is a minor phase with a modal abundance of up to 1.7 per cent (Stone and George, 1978). Zinnwaldite, amblygonite, triphylite and lithiophylite, have also been identified in 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 zones of varying lithium concentration or grade observed in the pluton. The resource estimate for the entire pluton (92.5 km^2) is about 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 about 3.3 million tonnes of lithium (Table 1).

Mineralogical studies showed that nearly all 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 existing 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. Waller (1889) first determined lithium in samples from Meldon, reporting a whole-rock value of 0.7 wt. % lithium oxide (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 aplite body is steeply-dipping (50°) and has a strike length of about 3.3 km and a thickness of about

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

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 al., (1987) estimated the Meldon Aplite to contain approximately 45 400 tonnes of lithium. However, Hawkes et al., (1987) cite several reasons 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 of the companies, British Lithium Ltd, are focussed on extraction of lithium from zinnwaldite found in the St Austell Granite. The company are currently working to define a JORC-compliant resource estimate for their Greenbarrow deposit and progress towards a full feasibility study. To date (September 2022) a resource estimate for Greenbarrow has not been publicly declared. The company established a pilot-plant in 2021 and produced a small quantity of high-purity lithium carbonate in January 2022 (British Lithium Ltd, 2022).

Cornish Lithium Ltd, are investigating both hard-rock and geothermal brine-related lithium resources in Cornwall. To date (September 2022) Cornish Lithium Ltd, have not declared a resource estimate for their geothermal brine operation at the United Downs site; however, the company have installed a pilot direct lithium extraction (DLE) plant that is currently being optimised to recover lithium from shallow (1–2 km deep) geothermal brines to produce lithium hydroxide (LiOH) (Cornish Lithium Ltd, 2022a). Cornish Lithium Ltd, have recently (2022) identified two additional sites to drill geothermal water research boreholes, one at Twelveheads that will be around 1.6 km deep (Cornish Lithium Ltd, 2022c) and one at North Downs, which will be around 2 km deep (Cornish Lithium Ltd, 2022b). In December 2021 Cornish Lithium Ltd, declared a maiden JORC-compliant inferred resource for their Trelavour hard-rock deposit, which currently stands at 51.7 million tonnes at 0.24% Li_2O (Cornish Lithium Ltd, 2021).

Lithium in the Trelavour deposit is hosted by mica, which Cornish Lithium Ltd, plans to extract using hydrometallurgical process technologies developed by Lepidico Ltd. The company plans to produce battery-grade LiOH from the lithium contained in the mica (Cornish Lithium Ltd, 2021).

North-east England

The Weardale Granite in County Durham, north-east England is a radiogenic (i.e. heat-producing) granite that was explored in 2004 for its geothermal energy potential (Manning et al., 2007). An exploration borehole, 955 m deep, was drilled at Eastgate, which intersected more than 700 m of granite at a depth of almost 268 m. Although, the granite itself does not contain any lithium-minerals, analyses of warm (c. 26°C) geothermal brine showed elevated concentrations of lithium (average of ten samples, 92.4 ppm) (Manning et al., 2007). Northern Lithium Ltd. have recently secured a mineral rights agreement to explore for and extract lithium from the geothermal brine associated with the Weardale Granite (Northern Lithium, 2019). Weardale Lithium Ltd. are also assessing the lithium potential of geothermal brines associated with the Weardale Granite, north-east England (Weardale Lithium, 2021).

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 researchers (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 (c. 40 m^2). The eastern part of this body is known as the Coilacreich Granite (c. 20 km^2), in which lithium-bearing mica is known to occur. Associated with the Coilacreich Granite is a much smaller (c.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

Although 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. To date, lithium has not been extracted on a commercial-scale 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 nineteenth century. Systematic exploration for lithium in the UK has been limited, although since 2017 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 define new hard-rock and geothermal brine-related lithium resources. Furthermore, work is progressing to assess the technical feasibility of commercial-scale extraction of lithium from hard-rock (mica) resources using hydrometallurgical processes and from brines using DLE.

A priority area for continued investigation is the lithium-mica-bearing areas of the St Austell Granite. The lithium resource potential of this area was highlighted in the 1980s, and ongoing exploration and a published resource estimate supports this assessment. The other target worthy of 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. Enrichment of lithium in similar LCT pegmatites elsewhere in the world provides a strong basis for evaluating this site further.

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