UK Critical Minerals Intelligence Centre

MINERALS FOR THE UK'S NET ZERO TRANSITION

The potential for graphite in the UK

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Introduction

Graphite is a form of carbon that occurs as black to steel grey, lustrous flaky aggregates, disseminated in metamorphic rocks or as veins with a fibrous or foliated texture (Taylor, 1994). Natural graphite has several specialist properties, such as high electrical conductivity, a high melting point, resistance to corrosion, and lubricity. This means it has varied industrial applications, including in electronics, lubrication, metallurgy and steel production (Robinson et al., 2017). Importantly, graphite is the primary material used for the anode of most lithium-ion batteries, and this is expected to be a major driver of increasing graphite demand in the coming years (International Energy Agency, 2021).

Global natural graphite production in 2020 amounted to an estimated one million tonnes, about 15 per cent lower than the previous year because of the influence of the COVID-19 pandemic (Idoine et al., 2022). China is the largest global producer of natural graphite, accounting for 65 per cent of total world production in 2020. Other significant producing countries include Brazil, India, Madagascar, Mozambique, Russia, Austria and Turkey (Idoine et al., 2022). Although

This profile provides an overview of the geological potential for graphite 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

forecasts of demand growth vary, it is estimated that by 2050 global demand for graphite will be at least five times greater than 2020 levels (World Bank, 2020). Natural graphite is on the UK's critical minerals list (Lusty et al., 2021) and is considered a 'critical raw material' by the European Union (European Commission, 2017). In common with some other industrial minerals, natural graphite has an industrially important synthetic equivalent, which is produced in electric furnaces from petroleum coke (Harben and Bates, 1990; Taylor, 1994).

The UK has no mine production of natural graphite and does not produce synthetic graphite. The UK is a small net importer of natural and synthetic graphite, with total imports of about 5500 tonnes of natural graphite and 13 800 tonnes of synthetic graphite in 2021 (Bide et al., 2022). In the UK graphite is typically used in aerospace applications, nuclear power generation and associated industries, in the petrochemical and automotive sectors, and for glass and steel manufacturing. Graphite anodes for batteries are not currently manufactured at commercial scale in the UK.

For commercial purposes, natural graphite is classified into three types, based on its morphology, grain size and crystallinity: amorphous; disseminated flake; and crystalline vein (Taylor, 1994). Graphite is a common component of metasedimentary rocks and all graphite deposits are formed by metamorphism, with geological conditions affecting the type of ore. Amorphous graphite deposits (made up of microscopic graphite crystals) result from relatively low-temperature metamorphism (typically at >300°C) of sedimentary rocks that are rich in organic matter (Robinson et al., 2017). Mexico and Russia are the main producers of amorphous graphite (Robinson et al., 2017).

Disseminated flake graphite forms when organic-rich sedimentary rocks undergo higher-temperature metamorphism (typically >500°C). This results in the pre-existing carbon-rich material being converted to flat, plate-like grains of graphite that can be up to 1 cm across, which are disseminated through the metamorphosed host rock. The grade of the graphite ore depends largely on the organic content of the original source rock. Flake graphite is mined worldwide in countries including Brazil, Canada, China, India, Mozambique and Madagascar.

Crystalline vein graphite (also termed lump or high-crystalline graphite) typically occurs as well-defined veins or pockets, containing more than 75 per cent graphitic carbon (Taylor, 1994; Harben and Kužvart, 1997). Graphite vein deposits form during high-grade regional metamorphism, in similar geological settings to disseminated crystalline flake deposits. They most commonly occur in crystalline metamorphic basement rocks and the carbon is introduced into the veins by fluids circulating during metamorphism. The only economically important deposits of this type worldwide are in Sri Lanka (Robinson et al., 2017).

UK mineral occurrences, exploration and production

Graphite is a widespread constituent of metamorphic rocks in the UK, particularly in Scotland. The most well-known historical production occurred at a vein graphite deposit at Seathwaite, in the Borrowdale valley of the English Lake District, in Cumbria. In the nineteenth century, it formed the basis of the renowned pencil industry in Keswick (Symes and Young, 2008; Ortega et al., 2010; British Geological Survey, 2019). The deposit comprises graphite veins, nodules and steeply inclined 'pipes' filling northwest-southeast trending faults that cut the host volcanic rocks (Barrenechea et al., 2009, Ortega et al., 2010). Mining at Seathwaite began at least as early as the late sixteenth century, continuing intermittently until it was abandoned in the late nineteenth century (Symes and Young, 2008). Production data is scarce, but operating for nearly 300 years, it must have produced a significant quantity of very pure lump graphite. Any potential subsurface extension of the mined deposit has not been explored since production ceased.

In Scotland, graphite has been worked at several localities on a small scale. Production data is scarce, and even the relatively important mines in the Highlands only appear to have produced a few tons of graphite annually. For example, the Glen Strathfarrar deposit is reported to have produced five tons of graphite in 1818 (Heddle, 1923), and a vein at Invergarry produced about two tons of graphite in 1825. It is reported that more than 100 tons of graphite was raised from the Craigman

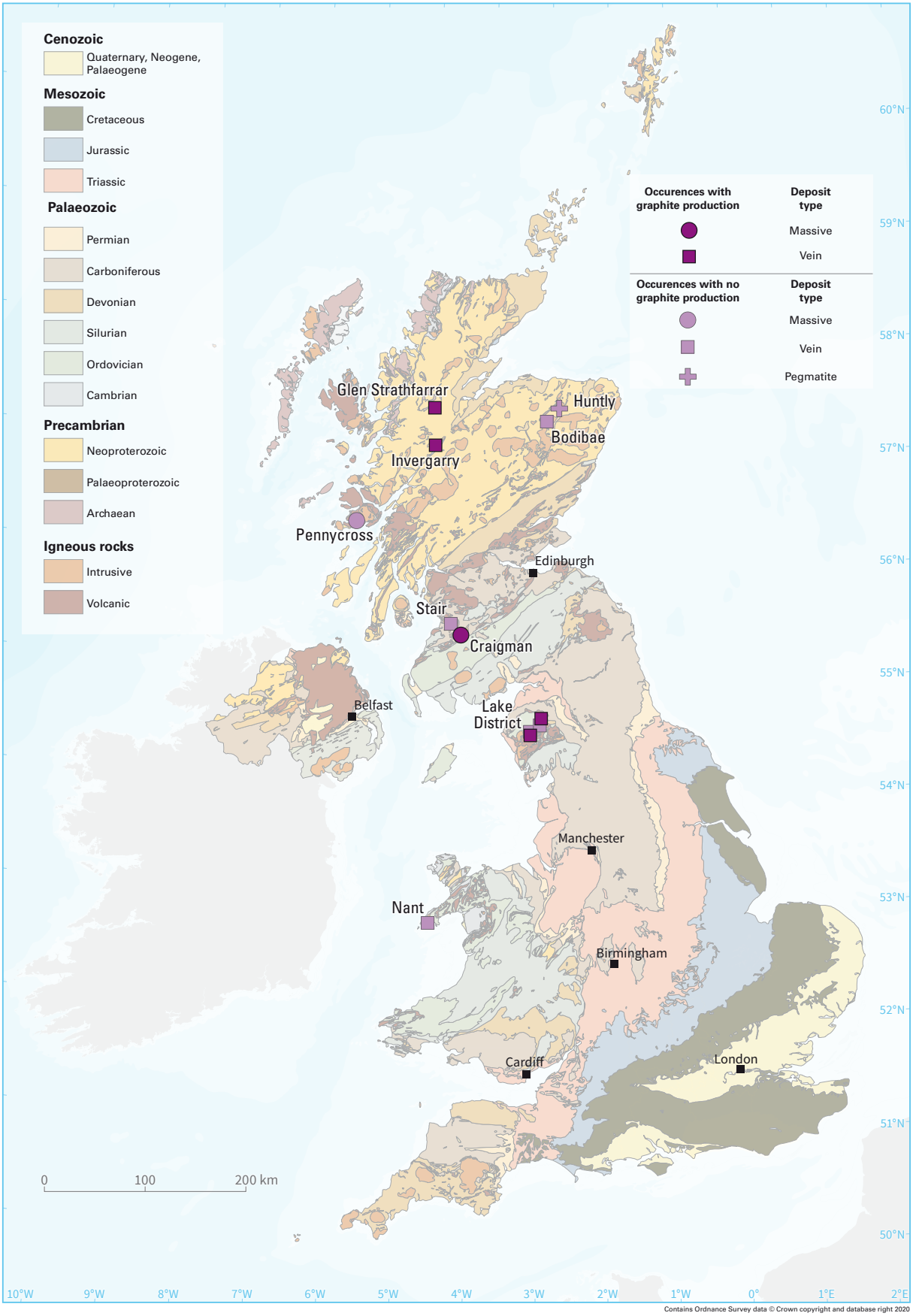

Figure 1 Location of the principal graphite occurrences in the United Kingdom.

coalmine near New Cumnock, in the Strathclyde region. However, this mine operated for about 100 years and the period over which this production took place is unclear (Strahan et al., 1917).

There has been no systematic or modern exploration for graphite in the UK and there are no deposits in which graphite resources or reserves have been reported.

North-west England

The Seathwaite deposit is highly unusual, as it is one of only two large graphite deposits hosted by volcanic rocks worldwide (Barrenechea et al., 2009). No other significant graphite veins have been described in the area, although Young (1987) indicates that minor amounts of graphite were obtained from an east-west graphite vein at Bannerdale near Keswick. Elsewhere in Cumbria, minor graphite has been identified in the country rock, and associated with sulfide mineralisation, for example, at the Dale Head Mine, Newlands Valley (Stanley and Vaughan, 1980) and the Wanthwaite Mine, St Johns in the Vale (Kingsbury and Hartley, 1958). Minor graphite has also been identified at Bowscale Tarn in the Caldew Valley, at Shap Granite Quarry at Shap, and at the Greenside Mine near Glenridding (Young, 1987). There is thus potential for graphite exploration at Seathwaite and elsewhere in the Lake District.

Elsewhere in England most graphite occurrences comprise observations of minor amounts of graphite that are rarely described in detail.

Scotland

Graphitic rocks are widespread in Scotland, with the mineral recorded in metamorphic rocks from many parts of the Highlands (Strahan et al., 1917; Tindle, 1998). Metamorphosed sedimentary rocks that are described as graphitic occur in many parts of the Dalradian succession of the Central Highlands (Stephenson et al., 2013) but there has been limited modern investigation of the potential for mineralisation. In Aberdeenshire, the Dalradian metasedimentary rocks are intruded by mafic-ultramafic igneous intrusions that are prospective for nickel and cobalt. Locally (e.g. at Bin Hill Quarry near Huntly), these intrusions host graphite veins and graphite-bearing pyroxenites that are considered to have formed when the heat of magmatic intrusion melted the metasedimentary rocks, allowing assimilation and redeposition of carbon as graphite (Gunn et al., 2015; Parnell et al. 2020). Reports of historical 'graphite mines' near Huntly and at Portsoy (Read, 1923; Heddle, 1923) indicate that these veins have been mined on a small-scale.

One of the most historically significant graphite deposits in Scotland is at Glen Strathfarrar, where vein-graphite occurs in fractures in folded metasedimentary rocks of the Moine Supergroup (Horne and Hinxman, 1914; Wright et al., 2012). Another historically worked graphite occurrence in the Highland region is at Invergarry, near the head of Loch Lochy. The graphite vein is reported to vary from 30–90 cm in width and be "of fairly good quality" (Strahan et al., 1917). Massive granular lumps of graphite have been found near Pennycross, on the Isle of Mull. Thin graphite-bearing veins are reported from near to Oban (Heddle, 1923). Graphite-bearing metasedimentary rocks also occur in several localities within the Lewisian Gneiss Complex of north-west Scotland (Parnell et al., 2021).

Graphite occurs at several locations in Ayrshire, including at Stair where it is associated with antimony and copper mineralisation (Heddle, 1923). At the Craigman coal mine massive and columnar graphite occurs in 'pockets' of variable shape and size (up to 90 cm wide), which are irregularly distributed within a dolerite intrusion. One of these pockets produced about 15 tons of graphite (Strahan et al., 1917).

Wales

Graphite is a common fine-grained constituent of marine sedimentary rocks in Wales. However, the only notable occurrence is the Nant manganese mine, on the Llŷn, in Gwynedd. Graphite specimens from this locality are held in the National Museum of Wales, but no information about the nature and abundance of the graphite is available (Bevins, 1994).

Resource potential

Graphite is a widespread constituent of many metamorphosed carbonaceous sedimentary rocks in the UK and minor graphite-bearing veins

occur at several localities in Northern England and Scotland. Despite this, there are no identified domestic resources or reserves and there has been no modern exploration for graphite. Current understanding suggests that the known vein deposits are unlikely to be of economic interest due to their small size and accessibility. However, there is a lack of modern information on the graphitic rocks of the UK, even though they are known to exist across a wide area, and further study is warranted.

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