



## RAW MATERIALS FOR DECARBONISATION

# The potential for cobalt in the UK

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### Introduction

Cobalt is a lustrous, silvery-grey metal with many physical and chemical properties that make it useful in a wide variety of chemical and metallurgical applications (Petavratzi et al., 2019). In the UK cobalt is used in high-performance alloys for the aerospace sector and in the cemented carbide, magnet and special steel industries. Cobalt chemicals are used in the manufacture of batteries, glass and ceramics (Petavratzi et al., 2019). The UK imports cobalt in several forms, chiefly as unwrought metal. In 2017 the total apparent consumption of cobalt in the UK amounted to about 1500 tonnes of contained cobalt metal (Bide et al., 2019).

Between 1993 and 2017 mine production of cobalt increased at a compound annual growth rate of seven per cent (BGS World Mineral Statistics Database). Global cobalt mine production in 2017 amounted to nearly 139000 tonnes (Brown et al., 2019). The Democratic Republic of Congo (DRC) dominates with a share of 59 per cent of the total in 2017. Other significant current producers include New Caledonia (seven per cent), China (6%),

Canada (5%) and Australia (4%). Cobalt produced in the DRC and Zambia is a by-product of copper

*This profile provides an overview of the geological potential for cobalt 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.*

extraction, while cobalt production in most other countries is a by-product of nickel mining. For example, in Cuba and New Caledonia cobalt is a by-product of nickel extraction from laterite deposits, while cobalt produced in Canada, Russia and China is from magmatic sulfide deposits. Cobalt is produced as the primary commodity from only a single operating mine, which is located at Bou Azzer in Morocco (Bouabdellah et al., 2016).

Cobalt can be found in economic concentrations in three principal deposit types: stratiform sediment-hosted copper-cobalt deposits; nickel-cobalt laterite deposits; and magmatic nickel-copper (-cobalt-platinum-group element) sulfide deposits (Naldrett, 2004; Mudd et al., 2013). Cobalt is also concentrated in a variety of other geological settings and deposit types, some of which were sources of cobalt in the past (Slack et al., 2017). These include: polymetallic cobalt-rich veins; iron oxide-copper-gold deposits; volcanogenic massive sulfide deposits; skarn and replacement deposits; cobalt-copper-gold deposits in metasedimentary rocks; black shale-hosted nickel-copper-zinc-cobalt deposits; and Mississippi Valley-type zinc-lead deposits. Most deposits in these environments have produced relatively small amounts of cobalt, commonly as a by-product of mining copper, nickel, silver, lead or zinc. Significant concentrations of cobalt also occur on the sea floor in iron-manganese-rich nodules and crusts, although to date no cobalt has been extracted from these on a commercial scale.

Cobalt occurs in a wide variety of minerals commonly in association with iron, nickel, copper and sulfur (Petavratzi et al., 2019). In the surficial environment cobalt also forms several oxide, hydroxide and carbonate phases.

## UK production and resources

Cobalt occurs as a minor constituent of base metal ores in several parts of the UK (Figure 1). However, where these ores were mined in the past copper, lead and zinc, and locally silver and nickel, were the main metals of interest. At a few abandoned mines in south-west England, north Wales, central Scotland and Cheshire a few hundred tons of polymetallic ores including cobalt were mined, mainly in the 18<sup>th</sup> and 19<sup>th</sup> centuries.

There has been no modern exploration for cobalt in the UK, although a few reconnaissance investigations of polymetallic mineralisation enriched in cobalt or with potential for cobalt enrichment have been undertaken. For example, the BGS undertook diamond drilling to investigate cobalt-bearing silver ores at Alva and Hilderston in central Scotland (Hall et al., 1982; Stephenson et al., 1983). There is currently no mine production of cobalt in the UK and there are no deposits in which cobalt reserves or resources have been reported.

## UK occurrences

In south-west England cobalt was recovered from nine mines from the mid-18<sup>th</sup> century to the 19<sup>th</sup> century, with a total production of a few hundred tonnes of ore (Rollinson et al., 2018). The mines with known production are: Wheal Sparnon near Redruth; Pelyn Wood Mine near Lostwithiel; Tretoil Wood Mine near Lanivet; Trugo Mine near St. Columb; Dolcoath and East Pool near Camborne; Great Dowgas and St. Austell Consols near St. Stephen; and Pengreep, near Gwennap. Wheal Sparnon had the most significant production, from a so-called 'cobalt lode', which was mined solely for cobalt. The ore was mainly roasted to produce cobalt oxides for use in the pottery industry (Jenkin, 1979; Rollinson et al., 2018). Cobalt at these mines in Cornwall is associated with lead, zinc, silver, uranium, antimony, manganese, iron, bismuth and nickel in late mineralised fractures known as cross-courses, which cut across the main copper and tin orebodies (Rollinson et al., 2018). Cobalt-rich mineralisation has also been reported in copper-lead-zinc-silver ores associated with the Wheal Lushington mines at Porthtowan near St Agnes (Rollinson et al., 2018). Mineralogical studies have identified abundant cobaltite (CoAsS) and subordinate erythrite ( $\text{Co}_3(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$ ) in these ores.

In Cheshire, small amounts of cobalt were recovered from copper deposits in Triassic sandstones at Alderley Edge in the early 19<sup>th</sup> century and at Clive in Shropshire (Bateson et al., 1982; Warrington, 2012). There is no information on the amount of ore extracted or metal produced from the mines in this district prior to 1857 (Warrington, 1981). In one of the mines at Alderley Edge, cobalt is concentrated in a series of north-south trending faults. This mine has recently been

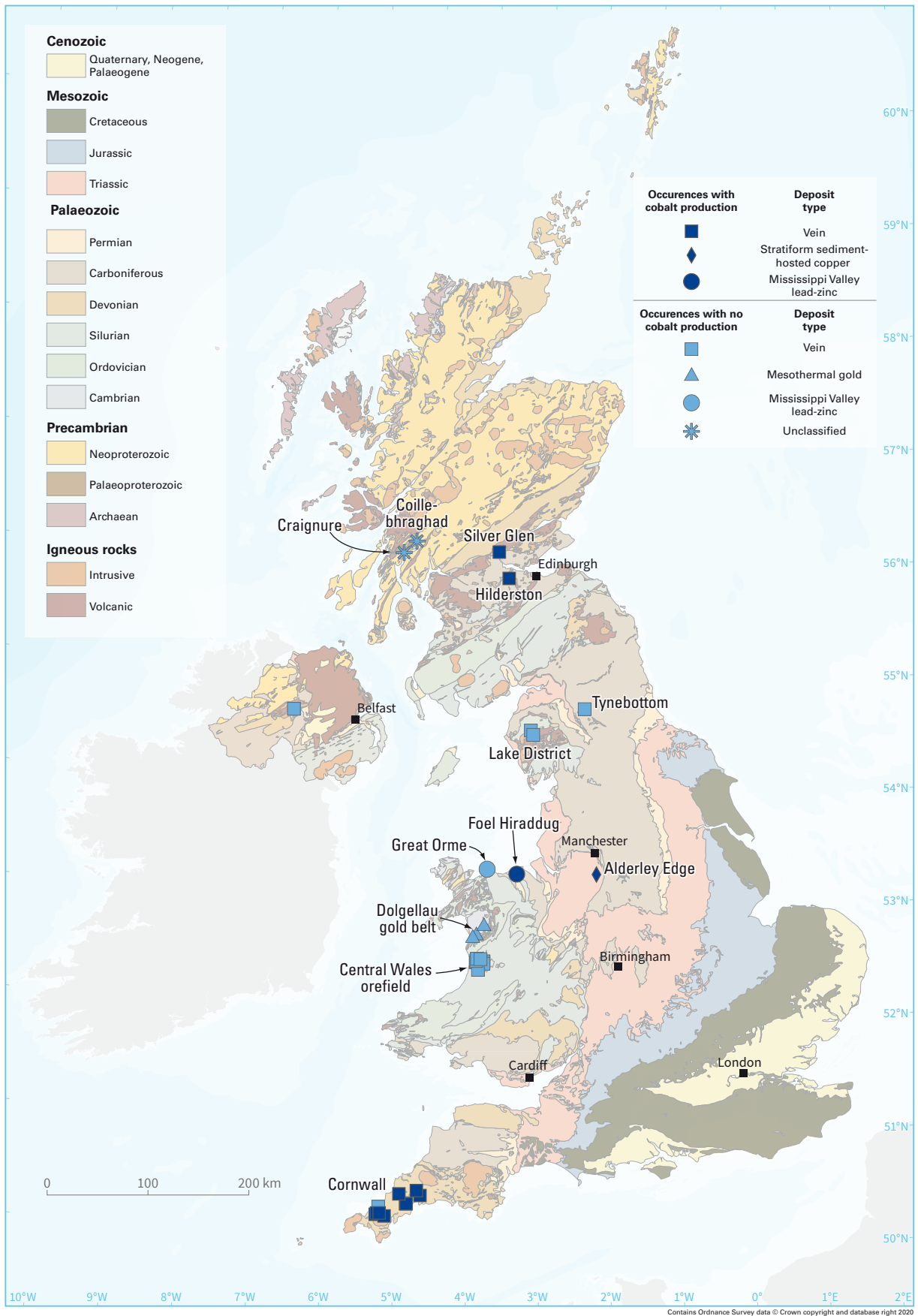


Figure 1 Location of the principal cobalt occurrences in the United Kingdom.

named the Cobalt Mine but there is no data on the cobalt content of the ores nor on the scale of past production (Derbyshire Caving Club, 2019). Warrington (2010) described asbolane  $((\text{Ni},\text{Co})_{2-x}\text{Mn}^{4+}(\text{O},\text{OH})_4.n\text{H}_2\text{O})$  as common, gersdorffite (NiAsS) as uncommon and erythrite as rare at Alderley Edge.

In the Lake District ores from Scar Crag and Dale Head North have high reported cobalt contents (Stanley and Vaughan, 1980 and 1982; Ixer et al., 1979). Cobalt extraction was attempted in the mid-19<sup>th</sup> century at Scar Crag, which was also called the 'cobalt mine', but this was never successful (Postlethwaite, 1913). Cobalt is associated with a chalcopyrite-pyrite-arsenopyrite assemblage and is incorporated in skutterudite  $((\text{Co},\text{Ni})\text{As}_{3-x})$  and sulfarsenides, such as alloclasite  $(\text{Co}_{1-x}\text{Fe}_x\text{AsS})$ , glaucodot  $((\text{Co}_{0.50}\text{Fe}_{0.50})\text{AsS})$  and cobaltite (Ixer et al., 1979; Stanley and Vaughan, 1982). A silver-nickel-cobalt mineral association has been described from the disused lead mine at Tynebottom, Garrigill, near Alston in the North Pennine Orefield (Ixer and Stanley, 1987). These ores occur in the Brigantian age (Carboniferous) Tynebottom Limestone, which rests on the Whin Sill in this area. Several cobalt-bearing minerals have been reported from this locality, including cobalt and nickel arsenides, sulfarsenides and sulfantimonides. Small amounts of nickel-cobalt mineralisation comprising niccolite (NiAs) accompanied by 'smaltite' (possibly skutterudite or cobaltite) have been recorded with copper ores in the Bonser vein and in the Paddy End section of the mines near Coniston in the Lake District (Russell, 1925; Young, 1987).

In the 18<sup>th</sup> century cobalt ores were mined on a small scale with silver at Silver Glen, near Alva, in Perthshire, Scotland. The mineralisation occurs in veins related to Permo-Carboniferous east-west-trending faults in late Devonian volcanic rocks. The cobalt mainly occurs as clinosafflorite  $(\text{Co},\text{Fe},\text{Ni})\text{As}_2$ , a rare form of safflorite (Hall et al., 1982; Moreton, 1996). Cobalt was also reported from the Hilderston mine, near Linlithgow in West Lothian, central Scotland, where it is also associated with silver and nickel. As at Silver Glen, mineralisation occurs in Carboniferous east-west trending faults, but here it is hosted by Lower Carboniferous sedimentary rocks (Stephenson

et al., 1983). The Coille-bhraghaid and Craignure copper mines, near Inverary in western Scotland, are reported to have also produced nickel-bearing minerals, pyrrhotite and pentlandite, which contained trace levels of cobalt. These deposits are associated with a suite of mafic intrusions in Neoproterozoic Dalradian metasedimentary rocks (Coats et al., 1982).

In the Central Wales Orefield cobalt is a minor component of early polymetallic vein mineralisation, which is noted for its varied mineralogy (Mason, 1997). The main mining activity here focussed on lead, zinc, copper and silver. Cobalt occurs in various cobalt-nickel minerals such as cobalt pentlandite  $((\text{Co},\text{Ni},\text{Fe})_9\text{S}_8)$ , siegenite  $(\text{CoNi}_2\text{S}_4)$ , linnaeite  $(\text{Co}^{2+}\text{Co}^{3+}\text{S}_4)$  and millerite (NiS). Cobalt pentlandite has been recorded at several mines including: Erglodd, Brynyrarian, Loveden, Ystrad Einion, Esgairhir, Esgairfraith and Nantycagl (National Museum Wales, 2019a). In North Wales cobalt and nickel sulfides occur in epigenetic copper ores in Carboniferous dolostone at the Great Orme Mine, near Llandudno (Ixer and Stanley, 1996; National Museum of Wales, 2019b). However, cobalt production in Wales is only known from Foel Hiraddug (also known as Moel Hiraddug) near Dyserth, located about 30 kilometres east of Llandudno. Here the cobalt occurs as asbolane, a cobalt hydroxide, associated with manganese oxides and hematite in a clay-filled fissure hosted in limestone of Carboniferous age. In addition to working for hematite and pyrite, cobalt and nickel were also produced at this site. Mine production of cobalt ore is estimated to have been 264 tonnes between 1878 and 1880 (Foster, 1882; North, 1962). The orebody had a length of about 23 metres and an average width of about 0.3 metres (with a maximum of 3 metres). It was worked to a depth of about 73 metres and a second 'vein' was trialled to about 30 metres. Foster (1882) reported assays of ore parcels containing 1.0–1.8% Co and 0.4–1.1% Ni.

Minor cobalt mineralisation is present in several disused gold mines in the Dolgellau gold belt in north Wales (Mason et al., 2002). A complex four-stage paragenesis is recognised in this belt: the first comprises iron-cobalt-arsenic mineralisation, which is followed by a 'bonanza

gold' assemblage, rich in gold, silver, tellurium, lead, antimony and bismuth (Mason et al., 2002). Cobaltite is the earliest mineral to form in these deposits. It is widespread but erratic in concentration, being present in minor to trace quantities at several mines. Mason et al (2002) noted its conspicuous presence at the Vigna, Panorama and Gwynfynydd mines.

Recent commercial exploration for precious and base metal mineralisation in the Tyrone Igneous Complex in Northern Ireland has highlighted some potential for cobalt. Quartz-sulfide veins in a quarry in the Corvanaghan-Golden Hollow area were reported to contain up to 0.13% Co, 1.27% Cu and 50.3 grams per tonne Ag (Walkabout Resources, 2018).

## Resource potential

On the basis of the widespread occurrence of cobalt minerals in a variety of deposit types there is potential for undiscovered cobalt resources in several areas of the UK. These include the Lake District, North Pennines, Cheshire and north Wales. Elsewhere historic mining of cobalt in the UK has demonstrated limited economic potential, either because of the small size of the orebodies or because the cobalt grades were low. However, it is important to stress that no systematic exploration for cobalt has been undertaken in any of these areas and modern research aimed at assessing the abundance and distribution of cobalt has not been carried out.

A priority target for further investigation are Caledonian mafic-ultramafic intrusive rocks in north-east Scotland, which have been studied in the past for their potential to host economic nickel and platinum group metal mineralisation (Gunn and Styles, 2002). The known cobalt enrichment in similar rocks elsewhere in the world provides a strong basis for evaluating these rocks in Scotland. Furthermore, McKervey et al. (2007) reported cobalt values up to nearly 2000 ppm in nickel-copper sulfide ores from the Knock intrusion in Aberdeenshire.

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