UK Critical Minerals Intelligence Centre

RAW MATERIALS FOR DECARBONISATION

The potential for rare earth elements in the UK

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Introduction

The rare earth elements (REE) are a group of 17 chemically similar metallic elements that include the 15 lanthanides, spanning atomic numbers 57 (lanthanum) to 71 (lutetium), together with scandium (Sc) and yttrium (Y). They are soft, malleable, and ductile silver-coloured metals with high melting points and unusual magnetic and optical properties that make them useful in many chemical and metallurgical applications, for example in catalysts, glass and ceramics, super alloys, and permanent magnets (Wall, 2014).

Demand for REE, especially those commonly used in the production of electric vehicles and wind turbines, is suggested to increase by between three and seven times by 2040 (International Energy Agency, 2021).

Global production, demand, and recycling

Between 2011 and 2021, world mine production of REE, commonly reported as rare earth oxide production, more than doubled from approximately 109 000 metric tonnes (t) to 267 000 t (British Geological Survey, 2021). During this period, the number of countries producing rare earth oxides increased from five to ten with China's share of global production dropping from 96 per cent to 67 per cent (British Geological Survey, 2021). However, China is responsible for refining nearly 90 per cent of global REE supply (International Energy Agency, 2021). Global production of rare

This profile provides an overview of the geological potential for rare earth elements 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.

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earth oxides did not slow down throughout the COVID-19 pandemic with China producing an estimated 180 000 t followed by Myanmar, the USA, and Australia contributing 35 000 t, 25 800 t, and 15 970 t of rare earth oxides respectively (Idoine et al., 2023). From 2016 to 2019, the UK imported on average around 1200 t of rare earth compounds and alloys per year at an average value of approximately £20 million per year, imports dropped to 470 t and £8.7 million respectively in 2020 (Bide et al., 2022). Whilst exports during this period averaged 546 t per year with an average value of around £11.3 million per year, exports dropped to 160 t and £3.2 m respectively in 2020 (Bide et al., 2022). At the time of writing, the UK has one rare earth metal and alloy manufacturing facility in Cheshire, England. However, planning permission has been granted for the construction of a rare earth oxide separation refinery in Yorkshire, England.

Global demand for REE in clean energy technologies may cause more than a 40 per cent increase in demand for REE by 2040 (International Energy Agency, 2021). The need for powerful magnets in electric vehicles and wind turbines amplifies demand for REE, such as dysprosium, neodymium, praseodymium, and terbium. Whilst other REE, such as cerium, lanthanum, europium, and yttrium play key roles as catalysts and components of alloys and in the glass and electronics industries, including smart phone and LCD screens (Walters and Lusty, 2011). The complexity of REE end-products coupled with the mass of REE used across these products, which ranges from less than 1 mg to several kg, means that separation of individual REE from each other to yield a pure single element through recycling is difficult with less than 1 per cent of the REE used today being recycled (Eggert et al., 2016, Jowitt et al., 2018). However, commercial recycling of REE magnet scrap is due to commence in mid-2024 at the HyProMag facility in Birmingham, England.

Geological occurrences of REE

REE-bearing mineral deposits occur in a diverse range of igneous, sedimentary, and metamorphic rock types. There are over 200 REE minerals identified, however, only 13 of these can currently be processed and five of these are currently considered economic, namely bastnäsite ((Ce,La)(CO_3)F), monazite ((Ce,La,Nd,Th)PO_4), xenotime (YPO4), loparite ((Na,Ce,Sr)(Ce,Th)$(Ti,Nb)_2O_6$), and fluorapatite ($(Ca,REE)_5[(Si,P)O_4]_3F$) (Wall, 2018). Enrichment of REE in mineral deposits is typically a multi-stage process involving low degree partial melting of an enriched mantle source, magmatic fractionation (Anenburg et al., 2021), liquid immiscibility (Martin et al., 2013), and hydrothermal processes (Broom-Fendley et al., 2017). Subsequent redistribution and concentration through weathering, groundwater flow, and other surface processes may also be important (Zhukova et al., 2021). However, the environments in which the REE become economically concentrated can be broadly divided into two categories: (1) primary deposits associated with igneous and hydrothermal processes, for example those associated with carbonatites and alkaline igneous rocks which host the largest and highest grade REE deposits; and (2) secondary deposits formed by sedimentary processes and weathering, for example ion-adsorption clays and placers (Walters and Lusty, 2011).

UK mineral occurrences, exploration, and production

In the UK there are many documented occurrences of REE-bearing minerals. However, in most cases these occurrences comprise only minor low tenor REE enrichment over restricted areas. For example, many of these minerals are found as accessory phases in granites or lead-zinc-fluorite mineralisation in the Northern Pennine Orefield (Walters and Lusty, 2011). To date there has been no mine production of REE-bearing minerals in the UK, nor are there any deposits in which REE reserves or resources have been reported. Rock and drainage samples from Loch Borralan, Loch Ailsh, and Loch Loyal in Scotland were analysed for Ce, La, and Y (Shaw and Gunn, 1993). In the early 1990s BGS undertook an assessment of the economic potential of mudstone-hosted nodular monazite in south-central Wales (Smith et al., 1994). More recently a BGS-hosted MSc student reappraised drill core from the ultramafic section of the Loch Borralan Complex to further assess its potential as a REE resource (Griffith, 2011). In 2013 BGS studied the formation of late-stage allanite-bearing veins associated with the Loch Loyal Syenite Complex (Hughes et al., 2013, Walters et al., 2013).

Figure 1 Rare Earth occurrences in the UK (Deady, et al. 2023). Contains Ordnance Survey data © Crown copyright and database right 2024. OS AC0000824781 EUL. Contains NEXTMap Britain elevation data from Intermap Technologies. UKRI © BGS, 2023.

Wales

Monazite nodules are locally present in Lower Palaeozoic sedimentary rocks of the Welsh Basin. During the 1980s these were investigated by drainage surveys undertaken by BGS as part of the government-funded Mineral Reconnaissance Programme. The very high REE concentrations (>5000 ppm Ce) identified in some panned stream sediment concentrates were found to be due to the presence of nodular monazite. The areas with the highest REE concentrations (>10 000 ppm Ce) in panned samples include: the Harlech Dome in the Snowdonia National Park; the Preseli Hills south-east of Newport; and the Berwyn Dome west of Llangollen. However, the most extensive area of high-cerium anomalies is in south-central Wales, north of the Brecon Beacons National Park, where monazite nodules are known to occur in catchments that drain Ordovician and Silurian sedimentary rocks (Cooper et al., 1983, Cooper and Read, 1984, Read et al., 1987, Smith et al., 1994).

In 1994 BGS undertook a preliminary economic assessment of in situ nodular monazite in the Newcastle Emlyn area of south-central Wales. Despite the favourable chemistry of the nodules (i.e. high-levels of europium, and very low-levels of thorium and uranium) the density of one nodule per 15 cm^2 in rocks in the Newcastle Emlyn area is far too low to be of economic interest. Upgrading during fluvial transport and sorting has resulted in the concentration of nodular monazite in sediments over a large area of south-central Wales. In some areas concentrations were found to exceed 1 per cent monazite in the less than 2 mm sediment fraction, which equates to 20 kilograms of monazite per cubic metre in tributary drainage. However, five kilograms of monazite per cubic metre is more typical. These grades are comparable with minimum exploitable grades in other parts of the world where monazite is extracted (Smith et al., 1994).

North-west Scotland

The only significant area of carbonatites and alkaline igneous rocks, from which REE are typically extracted, occur in the north-west Highlands of Scotland (Figure 1). During the late 1980s and early 1990s the ultramafic sections of the Caledonian intrusive complexes at Loch Ailsh and Loch Borralan were investigated by BGS for their platinum-group metal (PGM) potential (Gunn and Styles, 2002). Assay data from Loch Ailsh show the complex is enriched in lanthanum and cerium with values highest in the late leucosyenites up to 3239 ppm and 3956 ppm respectively (Shaw et al., 1994). REE concentrations are typically lower in the pyroxenites with maximum values of 840 ppm La and 1456 ppm Ce. These rocks are also enriched in Th (up to 244 ppm) and U (up to 65 ppm). In the pyroxenite there is a significant correlation between Y and Zr; however, in samples of syenite, Y is instead associated with La, Ce, Zn, Ti, Mn, V and Ca, indicating the possible presence of complex REE-minerals, such as allanite (Shaw and Gunn, 1993). More detailed work is needed to fully understand the distribution of REE in the Loch Ailsh Complex, especially as the syenites were not systematically investigated in the PGM-focused studies undertaken by BGS.

The Loch Borralan Complex is located about 2 km south-west of Loch Ailsh and comprises a suite of nepheline syenites with minor pyroxenites, and a small calcite carbonatite (Figure 2) (Goodenough et al., 2021). A drilling programme was undertaken at the Loch Borralan Complex during the 1980s to assess phosphate potential (Notholt et al., 1985). A second phase of drilling was undertaken during the 1990s to assess the PGM potential of the complex (Shaw and Gunn, 1993). Analysis of drillcore from the first phase of drilling revealed significant amounts of apatite in the pyroxenite units (between 1 and 10 wt. %). The presence of REE in the apatite was also established at this time by XRFS analysis (Notholt et al., 1985). Both drilling programmes identified minor REE enrichment in some drillcore intersections, with maximum values of 739 ppm lanthanum and 1764 ppm cerium. The REE enrichment is associated with the highest concentrations of apatite making it the most abundant REE-bearing phase within the Loch Borralan Complex (Shaw et al., 1994). A selection of drillcore samples (n = 33) were reanalysed by ICP-MS to determine the REE content (Griffith, 2011). This study found that background REE (lanthanum +cerium) concentrations are highest in the pyroxenite units (median 345 ppm) and lower in the syenite units (median 277 ppm). It also established that apatite is the most important host of REE in

Figure 2 Magnatite rich carbonatite from Loch Urigill, Scotland. © Holly Elliott, 2017.

the pyroxenite units, whereas in the syenite units, allanite is the most abundant REE-mineral. Minor REE mineral assemblages have been found in metasomatised host-rock (fenite) surrounding the intrusion, demonstrating REE-enrichment of metasomatising fluids (Goodenough et al., 2021).

In 1990 a short reconnaissance survey was undertaken by BGS over the Loch Loyal Complex and the associated Cnoc nan Cuilean Intrusion located 130 km north-east of Ullapool, close to the village of Tongue. This was to investigate occurrences of REE-minerals previously identified by earlier BGS investigations in the region (Atkin, 1969). A small set of stream sediment and rock samples were collected and analysed for lanthanum, cerium, and yttrium. Two rock samples from the Cnoc nan Cuilean Intrusion returned very high REE concentrations, with up to 5667 ppm lanthanum and 19 785 ppm cerium in a heterogeneous basic syenite. Samples collected from catchments draining the Allt Liath area were also observed to have elevated REE concentrations, with maximum values of 1922 ppm cerium in a stream sediment sample and 1409 ppm cerium in a sample of panned concentrate (Shaw and Gunn, 1993). Detailed mapping and geochemical sampling to investigate REE in the Cnoc nan Cuilean Intrusion were undertaken by BGS in 2011 (Hughes et al., 2013). This study found the intrusion broadly comprises two lithological zones, a massive leucosyenite and a complex 'mixed' syenite zone which includes both melasyenite and leucosyenite. The study also established that allanite is the most abundant REE-mineral in the Cnoc nan Cuilean Intrusion where it mostly occurs in the mafic melasyenites and in cross-cutting biotite-magnetite veins (Hughes et al., 2013). Additional work confirmed that the REE are most enriched in the late-stage, hydrothermal veins in the Cnoc nan Cuilean Intrusion where they occur not only in allanite, but also in REE-bearing apatite, and minor ancylite and bastnäsite (Walters et al., 2013). These veins contain up to 2 wt. per cent total rare earth oxides but they are typically very thin and discontinuous and therefore unlikely to be economic.

Other REE occurrences

Nodular monazite is known to occur in an east–west-trending belt of Devonian sedimentary rocks in the Exmoor area of south-west England (Read et al., 1987). Compositionally the monazite nodules from south-west England are very similar to those found in south-central Wales (Cooper and Read, 1984). However, they typically have lower cerium contents and have not been studied as extensively as those in Wales (Smith et al., 1994).

Historical work in the Northern Pennine Orefield (NPO) identified the presence of REE-bearing mineral veins (Ixer and Stanley, 1987, Ixer et al., 1996)and elevated REE concentrations in fluorite associated with Pb-Zn mineralisation (Shepherd et al., 1982). In 2011 samples of fluorite from the NPO were analysed by BGS to assess the REE potential (Walters, 2011). Compared to samples of fluorite from other parts of the UK (e.g. Southern Pennine Orefield) fluorite from the NPO was found to contain relatively high concentrations of REE (up to 900 ppm). Of particular interest was the observed enrichment in yttrium (up to 310 ppm) and europium (up to 46 ppm) in samples from the Queensberry Ironstone Workings at Cowshill, Weardale. However, all values were found to be subeconomic (Walters, 2011).

Resource potential

Even though REE minerals are known to occur in the UK, many of them are quite rare and are typically found in minor amounts in a few localities. It is worth noting that REE have never been commercially extracted in the UK, nor has there been any systematic exploration for REE.

A priority target for further investigation is the Cnoc nan Cuilean Intrusion in north-west Scotland. The hydrothermal, allanite-bearing veins that crosscut the intrusion contain the highest REE grades recorded in the UK (up to 2 wt. per cent total rare earth oxide) (Walters et al., 2013). The known occurrence of significant hydrothermal, REE-mineralised veins associated with alkaline igneous rocks elsewhere in the world provides a strong basis for evaluating this area further. However, there is currently no commercial process for extracting REE from allanite. This, coupled with the thin and discontinuous nature of the veins, makes them unlikely to be economic.

It is also important to note that previous work by BGS on the Caledonian alkaline intrusions of northwest Scotland has focussed on the PGM potential of selected parts of these bodies. Systematic investigations over the entirety of Caledonian alkaline intrusions of the northwest Scotland complex are recommended to fully evaluate their REE potential.

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