UK Critical Minerals
Intelligence Centre

RAW MATERIALS FOR DECARBONISATION

The potential for platinum group elements in the UK

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Introduction

The platinum group elements (PGE) comprise platinum (Pt), palladium (Pd), iridium (Ir), osmium (Os), rhodium (Rh), and ruthenium (Ru). Chemically, the PGE are very similar, but their physical properties vary considerably, such as platinum and palladium being heat and corrosion resistant but soft and ductile, compared to the hard and brittle properties of ruthenium and osmium (Gunn and Benham, 2009).

The PGE are used in many industrial applications such as catalytic converters, explosives, fertilisers, refining of high-octane gasoline, crucible coatings, glass manufacturing and liquid crystal displays, hard disks, semiconductors, circuits, and capacitors for example. Other examples of PGE uses include medical implants such as pacemakers, bullion for investment, and jewellery (Hughes et al., 2021, Gunn and Benham, 2009). Vehicle production currently dominates the PGE market, but whilst the production of internal combustion engines is declining, the new demand for PGEs for fuel cell electric vehicles is rising (International Energy Agency, 2021).

Global production, demand, and recycling

Global mine production of PGEs in 2021 amounted to 472 metric tonnes (t), an increase of 41 t from

This profile provides an overview of the geological potential for platinum group 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.

Department for Business & Trade

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2020 and over 18 t more than the previous 4-year average (Idoine et al., 2023). The leading world mined platinum producers in 2021 are South Africa (141.6 t), Russia (21 t), Zimbabwe (14.7 t), Canada (7.6 t), and the USA (4.5 t) (Idoine et al., 2023). Palladium is predominantly mined in Russia and South Africa, with production figures for 2021 both approximately 85 t. Other countries producing considerable palladium include the USA (14.8 t), Canada (13.3 t), and Zimbabwe (12.6 t). PGEs are also produced in Russia, South Africa, Zimbabwe, Canada, and the USA. In Europe, PGEs are produced by Finland, Serbia, and Poland, with a total PGE mine production in 2021 of approximately 2.5 t, 0.12 t, and 0.015 t respectively (Idoine et al., 2023).

Current demand for PGEs comes from applications in the automotive, chemical (including petroleum), electrical and electronics, medical, and glass industries, as well as investment, and jewellery sectors (Hughes et al., 2021, Cowley, 2023). A dynamic material flow analysis characterising the global platinum cycle between 1975 and 2016 found that autocatalyst and jewellery use demand the most primary, or mined, platinum but that the glass industry requires the highest gross platinum demand if recycling is considered (Rasmussen et al., 2019). Total aggregated demand for platinum from 2016 to 2050 has been modelled taking into account least and most aggressive scenarios in the development of its uses with results suggesting an increase between 5 thousand tonnes (kt) and 51.4 kt, respectively with a median increase of 9.8 kt (Rasmussen et al., 2019). Despite the move away from internal combustion engines toward electric vehicles, forecasting indicates that demand for PGE in catalytic convertors will still be higher than that for fuel cells by 2040 (International Energy Agency, 2021). The UK, EU, USA, Australia, Japan, and Canada consider most PGEs to be critical raw materials meaning the commodity is important to that country's economy but also has considerable risk of supply disruption (Su and Hu, 2022, Lusty et al., 2021). This is likely due to PGE production being dominated by South Africa (61 per cent) and Russia (23 per cent) (Idoine et al., 2023). Hostilities between Russia and Ukraine have created significant risks to supply, augmenting pre-existing supply chain difficulties and causing prices to spike, especially palladium, for which Russia is the world's largest producer (Cowley, 2023, Idoine et al., 2023).

Recycling plays a crucial role in the PGE market, with a substantial proportion of global supply consisting of recycled platinum (21 per cent), palladium (33 per cent), and rhodium (32 per cent) in 2023 (Cowley, 2023). In general, recycling in the platinum market takes two forms: closed loop and open loop. During closed loop recycling, the platinum-containing product is owned by the industry through all life stages and that, in general, the same amount of platinum is returned to that industry post-recycling (Rasmussen et al., 2019, Cowley, 2023). The glass, petroleum refining, chemical production, and electrolyser sectors are essentially closed loop (Rasmussen et al., 2019, Cowley, 2023). Open loop recycling involves platinum being sold on the global market and then being used in any sector (Rasmussen et al., 2019, Cowley, 2023). Historically, approximately 25 per cent of total annual platinum supply originates from recycling, with approximately 80 per cent of that coming from autocatalysts, most of the remainder from jewellery, and minor amounts from electronic waste. However, a reduction in global recycling of platinum has been recognised since the COVID-19 pandemic due to lower than expected recycling of vehicle autocatalysts coupled with a reduction in jewellery recycling rates (World Platinum Investment Council, 2023).

UK export and refining

At present, the UK has no production of PGEs from mining. However, in 2020 the UK exported 97 tonnes of platinum with an estimated export value of £2.16 billion, primarily from refining imported materials and recycling (Bide et al., 2022). This tonnage is comparable to 57 per cent of global primary mine production of platinum the same year (Idoine et al., 2023). Furthermore, the UK refines PGEs (see Figure 1) and produces alloys for global manufacturers in automotive, electronics, and consumer industries (World Trade Organisation, 2021). In 2022, UK trade in precious metals which includes non-monetary gold, silver, platinum, and palladium, had an import value of £8.814 billion and export value of £32.131 billion (Donnarumma,

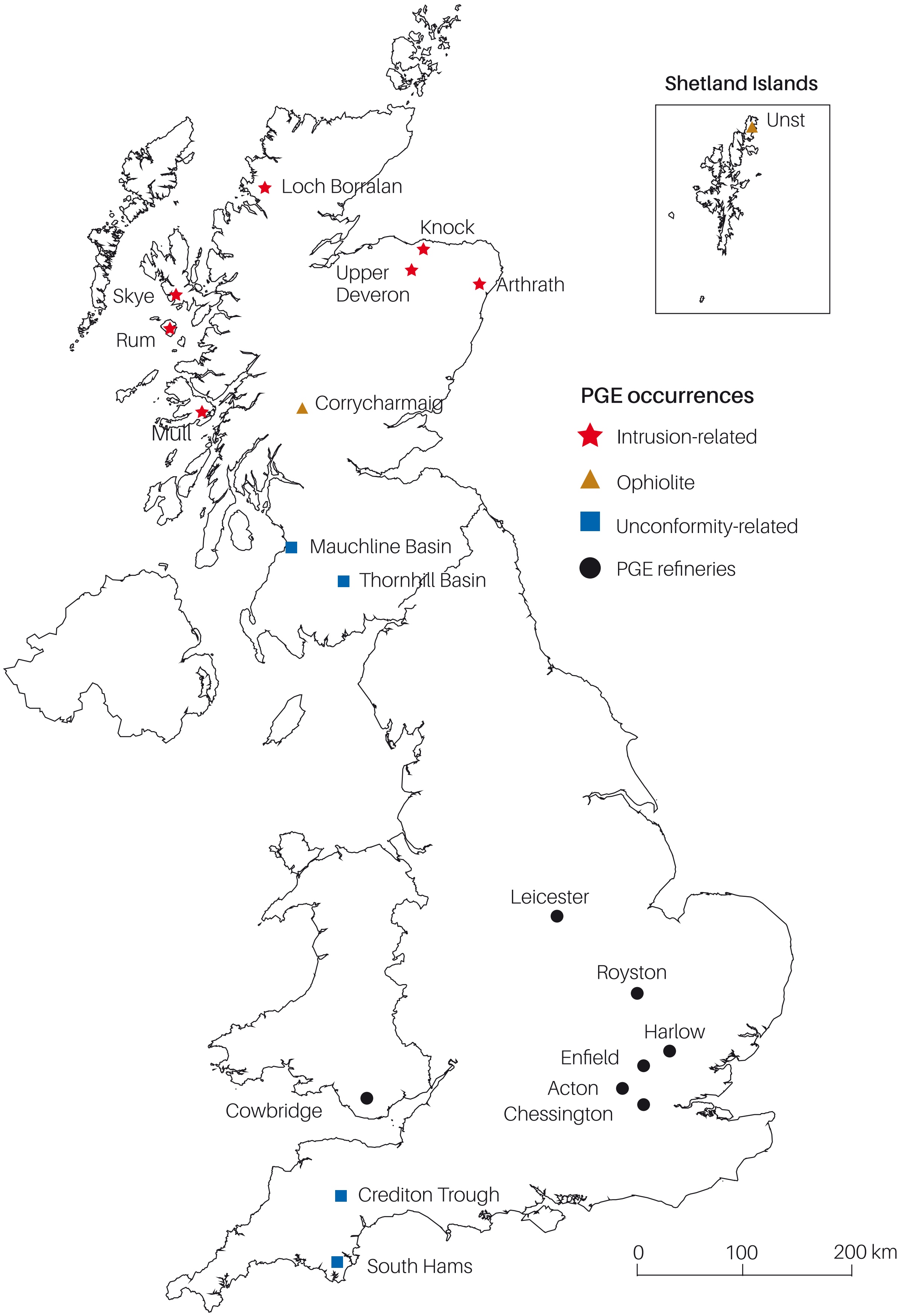

Figure 1 Identified platinum group element (PGE) occurrences and refinery sites in the UK (Gunn & Benham, 2009) (Contains Ordnance Survey data © Crown copyright and database rights 2024. OS AC0000824781 EUL). UKRI © BGS, 2023.

2023), making the UK a substantial exporter of these goods despite a lack of mine production.

Geological occurrence of platinum group elements

The average concentration of PGEs in Earth's upper crust is around 0.4–0.5 parts per billion (ppb) (Rudnick et al., 2003, Mungall and Naldrett, 2008). Ultramafic rock types, such as peridotite, are more enriched in PGEs, with an average concentration between 10 and 20 ppb (Zientek et al., 2017). Economic grades of platinum are typically 4 parts per million (ppm), requiring an enrichment factor of 10 000 compared to the Earth's crust (Mungall and Naldrett, 2008). The average grade in ore deposits mined primarily for their PGEs content vary between 5 to 20 ppm, but some hand specimens may reach hundreds of ppm (Zientek et al., 2017). At the time of writing, there are 169 recognised platinum group minerals capable of hosting at least one PGE in their crystal lattice (International Mineralogical Association, 2023). These platinum group minerals are typically either metal alloys (such as atokite, osmiridium, potarite), more commonly bonding with iron and less commonly with tin, copper, and lead; base-metal sulphide minerals (such as braggite, cooperate, laurite); or PGE-bearing accessory minerals (such as arsenides, antimonides, bismuthides, and tellurides) (Zientek et al., 2017, Gunn and Benham, 2009). Platinum group minerals are typically very fine-grained and not visible to the naked eye.

Economically-viable deposits of PGEs are rare, with only 12 producing countries in 2021 (Idoine et al., 2023). The major mined deposits can be split into two main types: magmatic nickel-copper-PGE sulphide; and placer deposits. Magmatic deposits can be PGE dominant (where PGEs are the primary target of mining or majority value) or nickel-copper dominant (where PGEs are produced as a by-product or minor value). Several other ore deposit types can host PGE, such as laterites, veins, ophiolites, and porphyry deposits, but are often less significant than magmatic and placer deposits (Gunn and Benham, 2009, Zientek et al., 2017).

Magmatic PGE-dominant sulphide deposits are formed by the segregation and accumulation of immiscible sulphide liquid from mafic or ultramafic magmas (Barnes et al., 2016). This happens when a fractionating magmatic body intruded into the crust has reached sulphide saturation point, causing an immiscible sulphide liquid to exsolve from the silicate melt. Sulphide droplets are denser than silicate magma, causing them to sink (Holwell and McDonald, 2010). PGEs, which are chalcophile elements, have an affinity for the sulphide melt causing PGEs to become at least 10 000 time more concentrated in sulphide melt compared to a silicate melt in equilibrium (Mungall and Naldrett, 2008). Therefore, PGEs and other chalcophile elements, such as copper, nickel, gold, silver, bismuth, and tellurium, are scavenged by the falling sulphide liquid droplets (Holwell and McDonald, 2010). These falling sulphide droplets may accumulate to form millimetre to metre scale layers or 'reefs' spanning up to several hundred kilometres in length, such as the Bushveld Complex, South Africa (Holwell and McDonald, 2010). The largest resources and reserves of PGMs can be found in the Bushveld Complex, which hosts many examples of PGE-dominant deposits, including the Merensky Reef, Upper Group 2 (UG2) chromitite, and Platreef. The Bushveld complex is responsible for over 60 per cent of global PGM production and nearly 75 per cent of global platinum production (Idoine et al., 2023). The Merensky Reef has been exploited for close to 100 years, however the higher PGE grade and presence of up to 28 per cent Cr_2O_3, has made the shallower, more rhodium rich UG2 reef a more favourable location for extraction of PGE (Mudd, 2023). The UG2 reef now accounts for the majority of PGE-bearing ore processed in South Africa (Anglo American, 2023).

Magmatic nickel-copper-dominant sulphide deposits are an important global source of nickel and can contain significant copper, cobalt, gold, silver, selenium, tellurium, and PGE (mainly palladium) as by-products (Eckstrand and Hulbert, 2007). The mafic and ultramafic bodies that host these deposits vary considerably in form and composition as follows: meteorite-impact mafic melt sheets with basal sulphide ore (e.g. Sudbury, Ontario); mafic sills and dykes feeding continental flood basalts associated with rifting (e.g. Noril'sk-Talnakh, Russia); komatiitic volcanic and intrusive rocks (e.g. Kambalda, Australia) (Gunn and Benham, 2009); and other mafic/ultramafic intrusions, such as Voisey's Bay, Labrador (Naldrett, 1997) and Kevitsa, Finland (Makkonen et al., 2017). Although the settings in which PGE deposits occur may vary, they share common features which allow for a generalised genetic model and a mineral systems approach to exploration to be developed and applied (Barnes et al., 2016).

Placer deposits are accumulations of dense minerals concentrated during sediment transport, sorting, and deposition. The formation of a placer deposit involves the erosion of a mineral deposit and subsequent separation of light and dense minerals under the influence of gravity and fluid flow (both water and air). These processes occur on a variety of scales from regional systems, such as beaches, to intermediate features, such as the inside bend of a river, and small-scale features, such as bedding laminae (Robb, 2020). Density contrast between heavy and light minerals during these processes make placer deposits important for resources, such as gold, tin, diamond, heavy mineral sands (rutile, ilmenite, zircon, garnet), and PGEs. Most commonly, PGE placers result from the erosion and weathering of enormous volumes of zoned mafic/ultramafic intrusions, but minor PGE placers have been identified eroded from ophiolitic terranes (Cabri et al., 2022). Grains of platinum-iron alloys in placers are deemed to be allogenic constituents and originate from primary magmatic mineralisation (Cabri et al., 2022).

UK mineral occurrences, exploration, and production

In the UK there are many documented occurrences of platinum group element minerals (see Figure 1), with the identification of intrusion, ophiolite, and unconformity-related occurrences. Several areas of the UK have been identified as potential areas of prospective interest for the platinum group elements, predominantly in Scotland (see Figure 2).

Scotland

Relatively low concentration PGE enrichment has been identified with magmatic nickel-copper ± cobalt sulphide ores in the northeast of Scotland (Gunn, 2007). The Arthrath intrusion near Ellon, 25 km north of Aberdeen, has a suggested a non-code compliant resource estimate of 17 Mt grading 0.21 per cent Ni and 0.14 per cent Cu (Gunn, 2007). A maiden drilling programme totalling over 1700 m of angled diamond drill holes has recently been undertaken by the current licence holder to further evidence these resource estimates (Minerals, 2023). Aberdeen Minerals also hold a licence over the Littlemill-Achencrieve area, near the Knock intrusion, which has historical estimates of 3 Mt grading 0.52 per cent Ni and 0.27 per cent Cu (non-code compliant) (Gunn and Styles, 2002) with values up to 574 ppb Au + Pt + Pd in a remobilised sulphide ore containing 1.5 per cent Cu and 0.7 per cent Ni (Fletcher, 1989, Fletcher and Rice, 1989). Other PGE-bearing lithologies have been identified in association with the Huntly intrusion, such as an area of graphite- and sulphide-bearing orthopyroxene-rich pegmatites containing high precious-metal concentrations up to approximately 700 ppb Au + Pt + Pd (Gunn and Shaw, 1992).

An exploration programme primarily focussed on phosphate potential over the Loch Ailsh alkaline intrusive complex in northwest Scotland identified localised PGE enrichment up to 859 ppb platinum and 43 ppb palladium in stream sediments (Notholt et al., 1985, Shaw et al., 1994). Further drilling at Loch Borralan indicated maximum levels of platinum and palladium of 328 ppb and 550 ppb respectively (Shaw et al., 1994). Whilst a further study suggested maximum PGE concentrations of up to 900 ppb platinum + palladium in pyroxenites of the Loch Borralan Complex (Styles et al., 2004).

PGE enrichment has been recognised across the North Atlantic Igneous Province (NAIP), most notably in Greenland at the Skaersgaard Intrusion (Nielsen et al., 2015). The NAIP extends south east into the UK, incorporating the layered mafic-ultramafic rocks in igneous centres on Rum, Mull, and Skye, which display elevated PGE concentrations (Power et al., 2000, Pirrie et al., 2000, Power et al., 2003, Hughes et al., 2015). In the Eastern Layered Series of Rum, chrome spinel layers and interstitial sulphides host platinum group minerals with concentrations reaching a maximum of 2.5 ppm (Power et al., 2000). A BGS-led Mineral Reconnaissance Programme (MRP) survey was undertaken to assess the nature of near-shore marine deposits off the coasts of Rum and Skye considered to have been eroded from these rocks (Gallagher et al., 1989). The topmost 1 metre of these marine deposits are estimated to

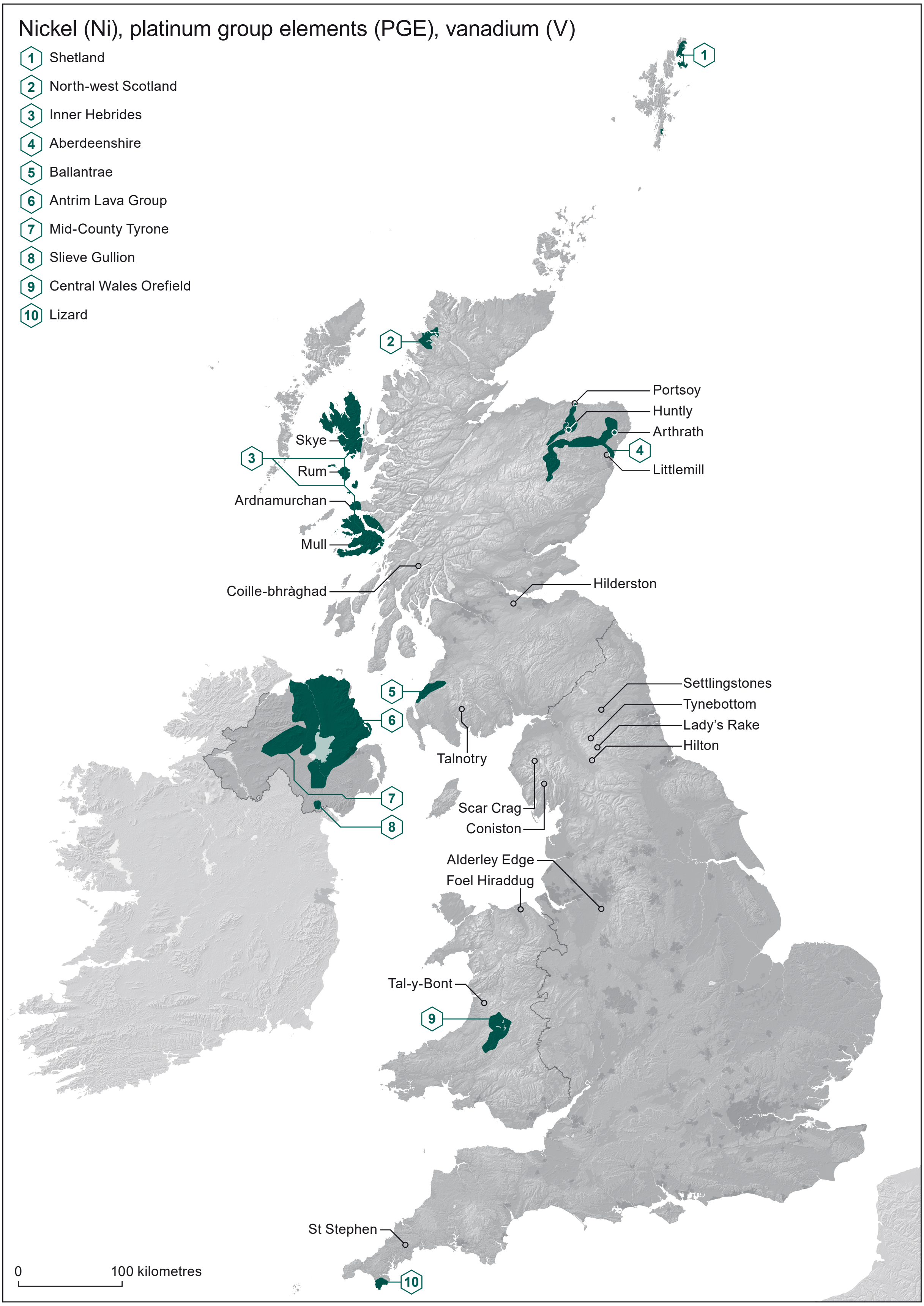

Figure 2 Areas of the UK that have been identified as prospective for Ni, PGE, and V (Deady et al., 2023). Contains Ordnance Survey data © Crown copyright and database right 2024. OS AC0000824781 EUL . Contains NEXTMap Britain elevation data from Intermap Technologies. UKRI © BGS, 2023.

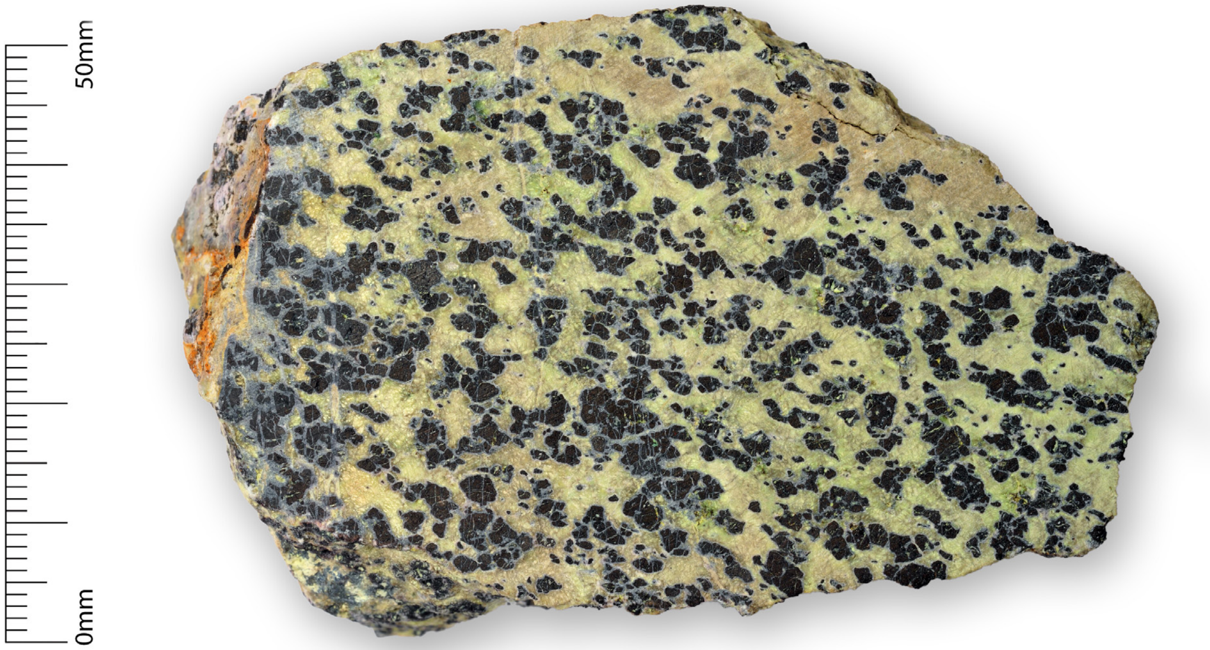

Figure 3 Hand sample of high-grade platinum-bearing chromite ore from the Unst Ophiolite, Shetland. Sample collected by Gus Gunn during Mineral Reconnaissance Programme. UKRI © BGS, 2010.

comprise approximately 9 Mt of sand containing 70 kt of chrome spinel averaging at a grade of around 1 per cent Cr, up to 2 Mt of olivine averaging a grade of around 25 per cent, and platinum + palladium concentrations up to 100 ppb (Gallagher et al., 1989).

Significant PGE enrichment has been identified at several levels within the Unst ophiolite in Shetland: a sequence of mafic and ultramafic rocks with an aggregate thickness of approximately 7 km. During the 1980s, high PGE concentrations were reported in the Unst ophiolite associated with podiform chromite ores (see Figure 3) which were mined between 1820 and 1945 (Gunn et al., 1984). The highest values, exceeding 100 ppm of both platinum and palladium, accompanied by ppm levels of gold and the other PGE, occur in spoil heaps at a locality known as Cliff. Elsewhere on Unst, PGE mineralisation more typical of ophiolites, dominated by osmium, iridium, and ruthenium, occurs in association with chromitites. The most notable example of this type is found at Harold's Grave where ppm levels of ruthenium and iridium were reported accompanied by relatively low platinum and palladium contents. Three small programmes of shallow drilling were undertaken by commercial companies between 1984 and 1999 to investigate the most promising PGE targets, but no significant high-grade PGE mineralisation was identified *in situ* (Gunn and Styles, 2002).

Rest of UK

The Magilligan Sill, a mafic intrusion on the north coast of County Londonderry, Northern Ireland, is part of the NIAP emplaced beneath the Palaeogene Antrim Lava Group and into sulphur-rich Mesozoic sediments. From 2014 to 2017, Lonmin (Northern Ireland) Ltd focussed on the Magilligan Sill as an exploration target for nickel – copper – PGE sulphides using Noril'sk as an analogue (Lindsay et al., 2019). The sill is approximately 60 m thick consisting of layers of dolerite and olivine gabbro with >150 μm size pentlandite, chalcopyrite, and pyrrhotite crystals containing less than 4 ppm total PGE, 1460 ppm Co, and 88 ppm Ag (Lindsay et al., 2019).

Ophiolite complexes, such as Ballantrae in South Ayrshire, Scotland and the Lizard in southern Cornwall, have been assessed for PGE potential, although PGE concentrations rarely exceeded 10 ppb (Stone et al., 1986, Hutchinson, 2001, Gunn and Styles, 2002, Prichard et al., 1996). Unconformity-related precious metal deposits on the boundaries of Permian red-bed basins in the South Hams district of Devon (Leake et al., 1992, Leake et al., 1991), related igneous rocks at Crediton Trough in Devon (Leake et al., 1994), and underlying more reduced strata in the Mauchline and Thornhill Basins of East Ayrshire and Dumfries and Galloway, Scotland (Leake and Cameron, 1996, Leake et al., 1997) have been explored. These deposits in the UK are small and show only slightly elevated PGE concentrations.

UK resource potential

UK resource potential for PGEs is low and the occurrences described above are minor relative to global deposits. If the nickel-copper deposits in northeast Scotland were mined in the future, it is likely that at best, PGEs would be a minor value by-product. However, PGE enrichment in these varied geological environments does lend an opportunity for research to be carried out to better understand their origins and to indicate how deposits of this type can be best processed to reduce energy consumption and environmental risk in other parts of the world.

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