UK Critical Minerals Intelligence Centre

MINERALS FOR THE UK'S NET ZERO TRANSITION

The potential for manganese in the UK

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Introduction

Elemental manganese is a silver to grey metal, which only occurs in nature as a compound with other elements (Holmes, 1994). Manganese is a ferrous metal that has chemical properties important for desulfurizing, deoxidising, and alloying. Accordingly, its main use globally and in the UK is in steel production, in which it is used as a purifying agent during iron-ore refining (removing oxygen and sulfur), and as an essential alloy that helps convert iron into steel (Cannon et al. 2017). Increasing amounts of manganese are now used in the emerging battery market.

Manganese is an abundant element in the Earth's crust and occurs in more than 300 minerals, however, only a few are of economic importance (Harben and Bates, 1990). Manganese has similar chemical properties to iron, meaning it commonly occurs substituted in small quantities in iron minerals (Maynard, 2014). The most economically important manganese minerals are oxides, and include pyrolusite (MnO_2), psilomelane ($BaMn\ Mn_8O_{16}(OH)_4$), braunite ($3Mn_2O_3 \cdot MnSiO_3$) and manganite ($Mn_2O_3 \cdot H_2O$) followed by carbonates (e.g. rhodochrosite; $MnCO_3$) and silicates (e.g.

This profile provides an overview of the geological potential for manganese 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 and Trade as part of the UK Critical Minerals Intelligence Centre.

British Geological Survey

rhodonite; $MnSiO_3$) (Harben and Bates, 1990; Holmes, 1994). Manganese is transported and concentrated in a range of terrestrial and marine geological environments; meaning manganese mineralisation is diverse in occurrence, origin, mineralogy and geochemistry, and deposits are widely distributed globally (Harben and Kužvart, 1997; Nicholson et al. 1997). Land-based manganese deposits are associated with hydrothermal, sedimentary, volcanogenic, metamorphic, and surficial supergene processes (Harben and Bates, 1990; Suprema, 1997). Global manganese ore production in 2021 amounted to 56.1 million tonnes (BGS World Minerals Statistics 2023). South Africa is the largest global producer of manganese ore, followed by Gabon and China, accounting for 34 per cent, 16 per cent and 11 per cent of the total in 2021, respectively. The largest other producers are Australia, India, Brazil, Ghana, Ivory Coast, and Ukraine (BGS World Minerals Statistics 2023). Manganese is imported into the UK in several forms. Ferro-manganese and ferro-silico-manganese are imported in the greatest volumes, amounting to nearly 22 000 tonnes and 32 000 tonnes, respectively in 2017 (Bide et al. 2019). Geologically manganese is not scarce, with many deposits identified globally that could potentially be developed. However, resources and reserves are highly concentrated; for example, South Africa has 70 per cent of the world's identified resources and about 25 per cent of its reserves (Cannon et al. 2017). Manganese is not considered by the European Union to be a 'critical raw material', owing to its production in more than 25 countries (European Commission, 2017).

UK mineral occurrences, exploration and production

There is currently no extraction of manganese in the UK, but manganese was exploited in the past, mainly in south-west England, and north and north-west Wales. Minor deposits are found elsewhere in England and Scotland (Woodland, 1956). There has been no systematic or modern exploration for manganese in the UK. Domestic interest and investigations peaked during the two World Wars. However, Groves (1952) indicates that virtually nothing of the results from the World War I investigations survived for use in World War II. More extensive investigation of hematite and manganese ores in all parts of the UK took place during World War II. Annual UK manganese production was highly variable between 1881–1945, ranging from a few hundred tonnes to more than 22 000 tonnes in 1906. Greater demand during World War II resulted in production increasing from nil in 1940 to more than 20,000 tonnes in 1943, with all production during this period coming from Wales (Woodland, 1956). There is currently no mine production of manganese in the UK and there are no deposits in which manganese reserves or resources have been reported.

South-west England

Manganese-rich mineralisation in south-west England primarily occurs in two main areas: one lies between Launceston and Milton Abbot, extending for about 23 km from Lanescot Down, in the west, to Brentor, in the east; and the other is located around Exeter (Dines, 1956; Woodland, 1956). Much of the manganese production of south-west England seems to have been a by-product of iron-ore mining, with the operations typically producing between a few hundred and a few thousand tonnes of manganese ore over a period of one to several years (Dewey et al. 1923). The deposits of south-west England were exploited primarily between 1850–1880, until the discovery of larger deposits elsewhere in the world made them uneconomic (Woodland, 1956); therefore, production did not end because of exhaustion of the resources (Dewey et al. 1923). South-east of Launceston, the Chillaton and Hogstor Mine remained active until 1907, producing about 50,000 tonnes of ore associated with iron ore (Dines, 1956). South-west England is estimated to have produced about 100 000 tonnes of manganese ore in total (Alderton, 1993). Most mines in the Milton Abbot area were for primary manganese production. Woodland (1956) indicates that in the Milton Abbot area the mineralisation is patchy and irregular, making development challenging, and on average each of the mines have produced only about 100 tonnes of ore.

The geology of the area is dominated by the Carboniferous rocks of the Culm Supergroup, primarily mudstones, containing chert beds, lavas, and mafic intrusives, of mainly doleritic

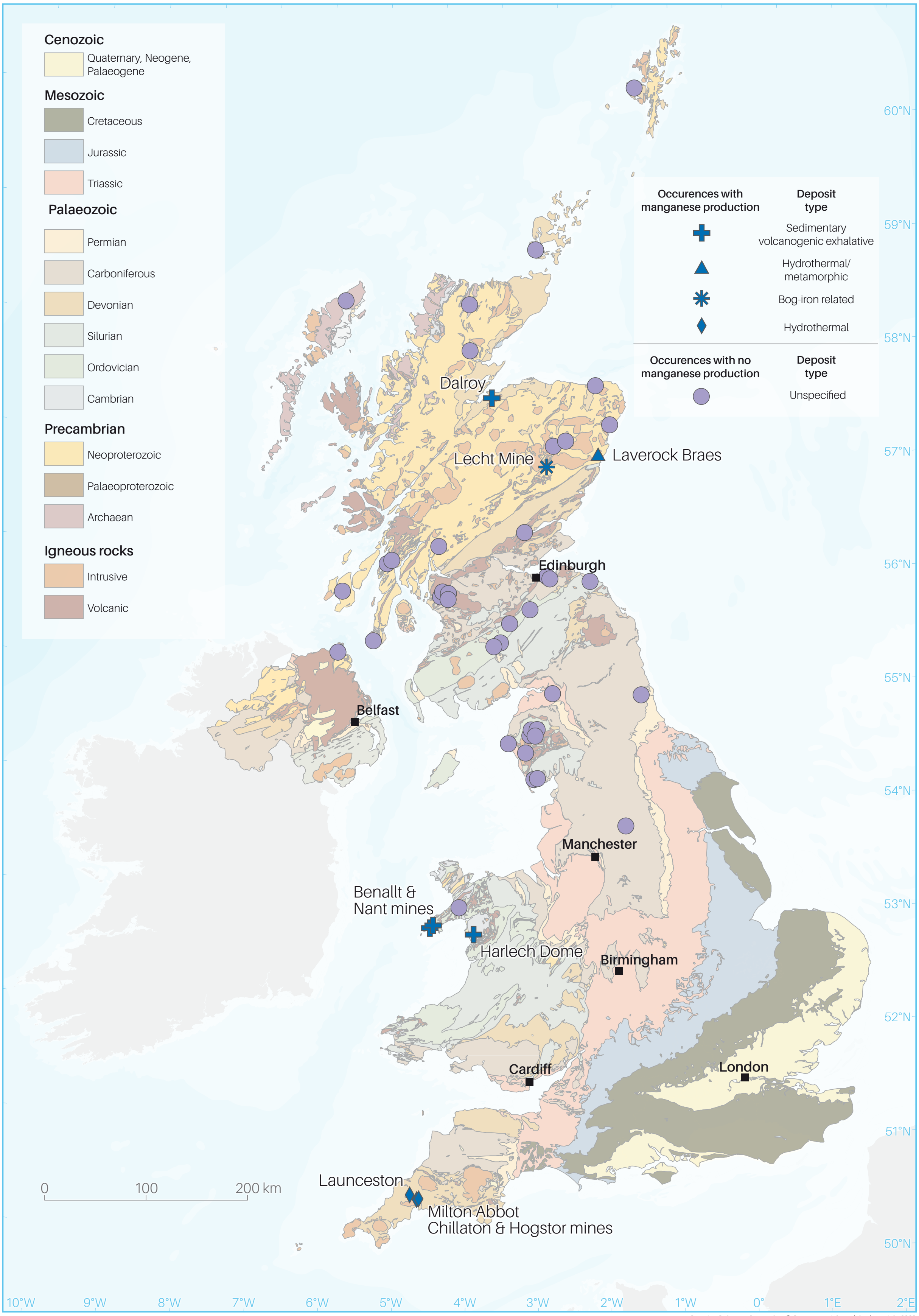

Figure 1 Location of the principal manganese occurrences in the United Kingdom.

composition. Dines (1956) indicates that the manganese deposits are characterised by: i) their occurrence in cherty units within the mudstones; ii) by a close association in these units with mafic intrusive rocks; iii) by the presence of narrow, ramifying veins of comb quartz; and iv) their irregular form, which may result from the alteration and localised replacement of the more siliceous sedimentary units. The irregular shaped ore zones are commonly linked by irregular fractures that are coated or impregnated with manganese oxide. There has been no modern systematic study of the manganese mineralisation. Dines (1956) considered it to be related to the basic igneous intrusions, common in the Culm Supergroup, proposing that either these were the source of manganese-rich hydrothermal fluids; or that thermal metamorphism associated with their emplacement caused remobilisation and segregation of manganese originally contained within the cherts.

Wales

Major occurrences of manganese mineralisations in Wales are located on the Llyn Peninsula and at the Harlech Dome. Around Rhiw, on the Llyn Peninsula, the mineralisation is of volcanogenic exhalative origin occurring as a series of stratabound lenticular bodies hosted by Lower Ordovician mudstones associated with high-level basic intrusions (Gibbons and McCarroll, 1993). The lenses are dislocated with a complex mineralogy due to later deformation and alteration of the sediment pile. Major accumulations in this region were mined at the Benallt and Nant mines, from about 1880–1928, and again during World War II.

The manganese resource potential of the Benallt and Nant mines was re-examined during World War II, and detailed descriptions, plans and sections for these old mines are available (Groves, 1952). The Nant orebody was found, following dewatering of the mine, to be largely worked out. In contrast, at Benallt, the Ministry of Supply re-opened one of the numerous old shafts and undertook extensive underground diamond drilling and development work. This wartime phase of activity at Benallt produced some 62,000 tonnes of manganese ore up to its final closure in 1945 (Down, 1980; Brown and Evans, 1989). The presence of additional mineralised bodies at depth was investigated by BGS's Mineral Reconnaissance Programme (MRP), sponsored by the Department of Trade and Industry, which completed more than 20 projects in Wales between the mid-1970s and 1997 (e.g. Leake and Marshall, 1994). The main targets were copper, lead, zinc and gold, but included geophysical and geochemical investigations and drilling of the manganese deposits of Rhiw during the late 1980s (Cooper et al. 2000). No significant accumulation of manganese at depth was found and anomalies were attributed to stratabound ironstones (Brown and Evans, 1989).

The Harlech Dome deposit comprises a series of Mn-rich strata dispersed within a thick succession of lower to middle Cambrian turbiditic sandstones. These are overlain by late- middle Cambrian alternating mud-rich and sand-rich units grading into anoxic organic-rich turbidites shallowing upward into mudstone (Waldron et al., 2011). The whole sedimentary succession is exposed within the hinge of the periclinal Dolwen anticline. The main ore bed is part of the Hafotty Formation within the middle section of the sedimentary succession, averaging 40 cm in thickness and covering an area as large as 190 km^2 (Bennet, 1987). The ore consists mostly of Mn-bearing carbonate, spessartine, and quartz, averaging 39 wt.% MnO (Bennet, 1987). Interpretation of geochemical signature, lithofacies and stratigraphic succession showed these Mn-rich horizons to be akin to sedimentary exhalative deposits, with metal precipitation as oxides from a low-temperature hydrothermal brine, later transformed into carbonates during early diagenesis (Bennet, 1987). Ore was extracted along exposed localities of these horizons during the nineteenth and twentieth century, whilst other minor accumulations of spessartine higher in the stratigraphy have also been extracted (Bennet, 1987).

Lake District

Numerous occurrences of manganese oxides, manganite and other manganese ores have been reported from the Lake District in association to mines producing dominantly lead and iron, but also graphite and aluminium (Young, 1987). No mine produced manganese as a primary resource in these localities.

Scotland

In Scotland, limited production occurred at the Lecht Mine in the mid-19th century for a couple of years until discovery of large, high-purity manganese deposits in Germany and Russia rendered the Lecht operation uneconomic. The Lecht deposit occurs in the Argyll Group of the Dalradian Supergroup in the northeast of Scotland and has been successively interpreted as (i) the expression of a distal SEDEX deposit associated with an undiscovered buried Pb-Zn deposit, (ii) a gossan formation, and more recently as (iii) a bog ironstone related deposit (Nicholson, 1987). The later supergene origin for this deposit is supported by textural, structural, and mineralogical observation, as (i) the mineralisation exhibits typical regolith profiles and enrichment horizons, (ii) distribution is controlled by the porosity of the hosting breccia, (iii) the mineralisation is coating rock fragments without any sulfide precursor or gangue, and (iv) Fe and Mn minerals of supergene origin are largely present (such as chalcophanite, woodruffite, and lithiophorite). It is therefore considered that the deposit formed as a superficial bog-iron deposit within a valley, accumulating metals from the weathering and leaching of stratabound enrichments in adjacent Dalradian metasedimentary rocks under a sub-tropical climate, with metal-rich waters seeping and precipitating into the underlying brecciated formation (Nicholson, 1987, Chacksfield et al., 1997). Exploration boreholes drilled around the old working area of the mine reported the presence of a stratabound, 58 m thick, Fe-Mn rich zone in the metasedimentary rocks associated with a high content of spessartine garnet (Chacksfield et al., 1997).

Manganese was also extracted at Laverock Braes quarry near Bridge of Don, Aberdeen, in the first half of the nineteenth century. At this time, manganese constituted an ingredient for the preparation of bleaching agent for cloth or was used as a chemical purifier for glass manufacturing (McMullen, 2019). Overall production estimates for this mine are scarce though 1955 tons of ore were excavated by 1809, before its closure in the 1820s and reopening in the 1840s (McMullen, 2019). The manganese ore occurs in migmatitised psammitic and semipelitic metasedimentary rocks of the Aberdeen Formation and is described as 'irregular beds, rounded concretions, or anastomosing films in the rock, accompanied by small quantities of sulphates of barytes' (Annon, 1838 in McCullen, 2019). Located on the edge of the Ordovician Aberdeen Pluton, a two-mica granitic intrusion, the quarry shows presence of minor sheets and veins of granite within the metasedimentary rocks hosting the ore, though no clear genetic relationship has been established between the ore and the intrusion (McCullen, 2019).

At Dalroy, near Inverness, a localised stratiform Mn-rich bed was briefly mined in the 1920s. Exposure was however very limited as the bed varied in thickness from a few centimetres to two metres with a lateral extent of tens of metres. Buried discoveries extended the spread of the bed when exploration shafts were created (Nicholson, 1990). The Mn ore is commonly found overlying hematite beds within the Middle Old Red Sandstone formation of Devonian age. Nicholson (1990) suggests a hydrothermal origin for the Mn deposit based on mineralogy, textures and geochemical analysis, suggesting a sublacustrine hot-spring deposition like that currently observed in the East African Rift Valley lakes or Lake Taupo in New Zealand (Nicholson, 1990). Numerous other occurrences of manganese minerals are reported throughout Scotland though none justified any form of further exploration or extraction (Nicholson, 1989).

Resource potential

The main potential for manganese resources is in Wales. The stratabound Harlech Dome deposit constitutes the largest known accumulation of manganese in the United Kingdom, as the ore unit has been observed to be stratigraphically continuous over an area of 190 km^2. Although no consistent resource estimate has been carried out, grades and mineralogy are relatively well-known from peripheral extraction along exposed locations, though of lower grade and quantity than other deposits in Europe. This groundwork coupled to further drilling could form the basis for evaluating the potential for underground extraction of manganese in this area if domestic production is required.

Manganese is a common constituent of many mineralised systems of hydrothermal origin. As such its occurrence is common across the UK in association with Pb-Zn deposits, massive sulfides, and vein deposits. Further exploration of stratabound deposits in the Dalradian Supergroup of Scotland could highlight further accumulation of Mn, though preliminary exploration in the surroundings of the Lecht Mine did not find any significant geochemical anomalies. The extent and quality of Mn accumulations in these settings remains marginal and these occurrences are unlikely to be economic.

References

ALDERTON, D H M. 1993. Mineralization associated with the Cornubian Granite Batholith. 270–354 in *Mineralization in the British Isles*. Pattrick, R A D, and Polya, D A. (Eds.). (London: Chapman and Hall).

BIDE, T, BROWN, T J, IDOINE, N, and MANKELOW, J M. 2019. United Kingdom Minerals Yearbook 2018. *British Geological Survey Open Report*, OR/19/018. 63pp.

BROWN, M J, and EVANS, A D. 1989. Geophysical and geochemical investigations of the manganese deposits of Rhiw, western Llyn, North Wales: *British Geological Survey Report* WF/89/014. Mineral Reconnaissance Programme Report; 102.

BROWN, T J, IDOINE, N E, RAYCRAFT, E R, HOBBS, S F, SHAW, R A, EVERETT, P, KRESSE, C, DEADY, E A, and Bide, T. 2019. World Mineral Production 2013–2017. British Geological Survey, Keyworth, Nottingham.

CANNON, W F, KIMBALL, B E, and CORATHERS, L A. 2017. Manganese. In: SCHULZ, K J, DEYOUNG, J H, JR, SEAL, R R, II, and BRADLEY, D C. (eds). Critical mineral resources of the United States — Economic and environmental geology and prospects for future supply: *US Geological Survey Professional Paper* 1802, p. L1–L28, https://doi.org/10.3133/pp1802L.

CHACKSFIELD, B C, SHAW, M H, COATS, J S, SMITH, C G, and STEPHENSON, D. 1997. Exploration for stratabound mineralisation in the Argyll Group (Dalradian) of north-east Scotland. *Mineral Reconnaissance Programme Report*, British Geological Survey, No. 145.

DEWEY, H, DINES, H G, BROMEHEAD, C E N, EASTWOOD, T, POCOCK, R W, and WILSON, G V. 1923. Tungsten and manganese ores. *Special reports on the mineral resources of Great Britain*; 1. London : HMSO, 1923.

DINES, H G. 1956. The metalliferous mining region of south-west England. *Economic memoir of the Geological Survey of Great Britain*.

DOWN, C G. 1980. The manganese mines of North Wales. British mining; no.14. A monograph of the Northern Mine Research Society. Sheffield: *Northern Mine Research Society*.

EUROPEAN COMMISSION. 2017. Study on the review of the list of Critical Raw Materials Non-critical Raw Materials Factsheets. Luxembourg: *Publications Office of the European Union*.

GROVES, A W. 1952. Wartime investigations into the haematite and manganese ore resources of Great Britain and Northern Ireland. *Ministry of Supply, London*, 359p

HARBEN, P W, and BATES, R L. 1990. Industrial Minerals Geology and World Deposits. *Industrial Minerals Division, Metal Bulletin*.

HARBEN, P W, and KUŽVART, M. 1997. Industrial Minerals: A Global Geology. *Industrial Minerals Information Ltd*, London. 462pp.

HOLMES, R A. 1994. Manganese minerals. In: CARR, D D. (ed). Industrial Minerals and Rocks. *Society for Mining, Metallurgy, and Exploration*; 6th edition, p. 655–660.

IDOINE, N. et al. World mineral production 2017–2021. (British Geological Survey, Keyworth, 2023), https://nora.nerc.ac.uk/id/eprint/534316.

LEAKE, R C, and MARSHALL, T R. 1994. Reconnaissance drainage survey for base-metal mineralisation in the Lleyn peninsula, North Wales. *British Geological Survey Technical Report* WF/94/3 (BGS Mineral Reconnaissance Programme Report 132).

MAYNARD, J B. 2003. Manganiferous sediments, rocks, and ores. In: HOLLAND H D, and TUREKIAN, K K. (eds.). T*reatise of Geochemistry, volume 9, Sediments, Diagenesis, and Sedimentary Rocks*. Second edition, Chapter: 15, Elsevier, 289–308.

MCMULLEN, M. 2019. Manganite form Laverockbraes, Grandhome, Aberdeen. *Journal of the Russel Society*, volume 22, 11–29

NICHOLSON, K. 1990. Stratiform manganese mineralisation near Inverness, Scotland: A Devonian sublacustrine hot-spring deposit? *Mineral Deposita*, 25, 126–131.

NICHOLSON, K, HEIN, J R, BÜHN, B, and DASGUPTA, S. 1997. Precambrian to modern manganese mineralization: Changes in ore type and depositional environment. *Manganese Mineralization: Geochemistry and Mineralogy of Terrestrial and Marine Deposits, Geological Society Special Publication* No. 119, 1–3.

SUPRIYA, R. 1997. Genetic diversity of manganese deposition in the terrestrial geological record. In: NICHOLSON, K, HEIN, J R, BIIHN, B, and DASGUPTA, S. (eds.). *Manganese Mineralization: Geochemistr and Mineralogy of Terrestrial and Marine Deposits, Geological Society Special Publication* No. 119, 5–27.

WOODLAND, A W. 1956. The manganese deposits of the Great Britain. I*nternational Geological Congress. Mexico*, (20th: 1956). 197–218.