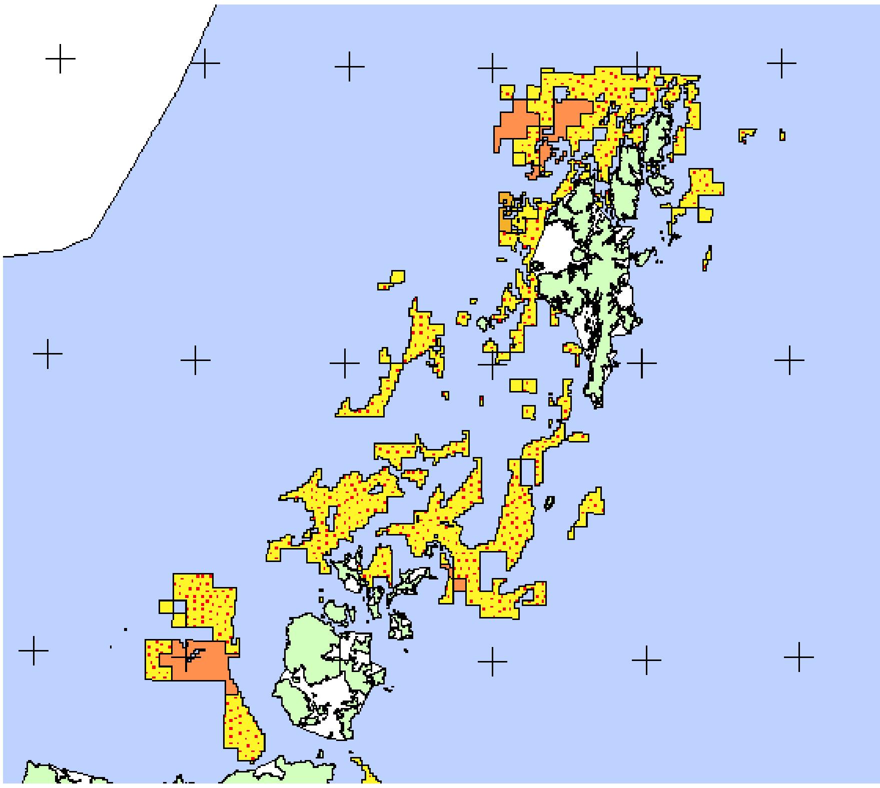
The Mineral Resources of Scottish Waters and the Central North Sea

Minerals and Waste Programme

Open Report OR/13/013



BRITISH GEOLOGICAL SURVEY

MINERALS AND WASTE PROGRAMME

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The Mineral Resources of Scottish Waters and the Central North Sea

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Map

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Marine aggregate resources around Shetland and Orkney

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Foreword

This report accompanies the mineral resource map of Scottish Waters and the Central North Sea (Green *et al*, 2013). It has been published as part of the research project *Mineral Resource Assessment of the UK Continental Shelf* commissioned by The Crown Estate. The map is one of a series that covers the UK Continental Shelf (UKCS).

Knowledge of mineral resources is essential for effective and sustainable planning decisions. The marine mineral resource maps provide a comprehensive, relevant and accessible information base. This information will allow all stakeholders (planners, industry and members of the public) to visualise the distribution of offshore minerals to a common standard and at a common scale, an important requirement of an integrated offshore planning system. The maps will also facilitate the conservation (safeguarding) of non-renewable mineral resources for future generations in accordance with the principles of sustainable development.

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1 Introduction

Minerals are naturally occurring raw materials essential for the development of a modern economy. However mineral resources are finite and can only be worked where they occur. As their extraction is subject to many constraints, it is important that society uses minerals in the most efficient and sustainable manner. Identifying the distribution of known mineral resources on the UK Continental Shelf (UKCS) and presenting them in a consistent fashion at a national scale allows minerals to be considered in the marine spatial planning process and permits more effective and sustainable management strategies to be developed.

The British Geological Survey (BGS) has undertaken a commission from The Crown Estate to prepare a series of mineral resource maps which cover the UKCS. Mineral resource information was compiled following a desk study of data held by the BGS and external sources. This report summarises the mineral resources depicted on the fourth of these maps - the area includes Scottish waters and extends south into the central North Sea. This area includes areas around Scotland where the Scottish Government have responsibility for planning as well as the North East marine plan areas as defined by the Marine Management Organisation (MMO).

The map has been produced by the collation and interpretation of a range of information, much of which is spatially variable and not always available in a consistent and convenient form. The map depicts mineral resources of current or potential future economic interest in the area. It comprises a 1:500 000 scale map (which accompanies this report) depicting marine aggregate (sand and gravel) resources on the sea bed, and three 1:2 500 000 scale maps (as annexes in this report) depicting coal and evaporite resources at depth beneath the sea bed as well as metallic minerals. These map scales are convenient for the overall display of the data. However, all the data are held digitally and therefore may be viewed at variable scales using a Geographical Information System (GIS). This allows for revision, updating and customisation of the information, as well as integration with other datasets.

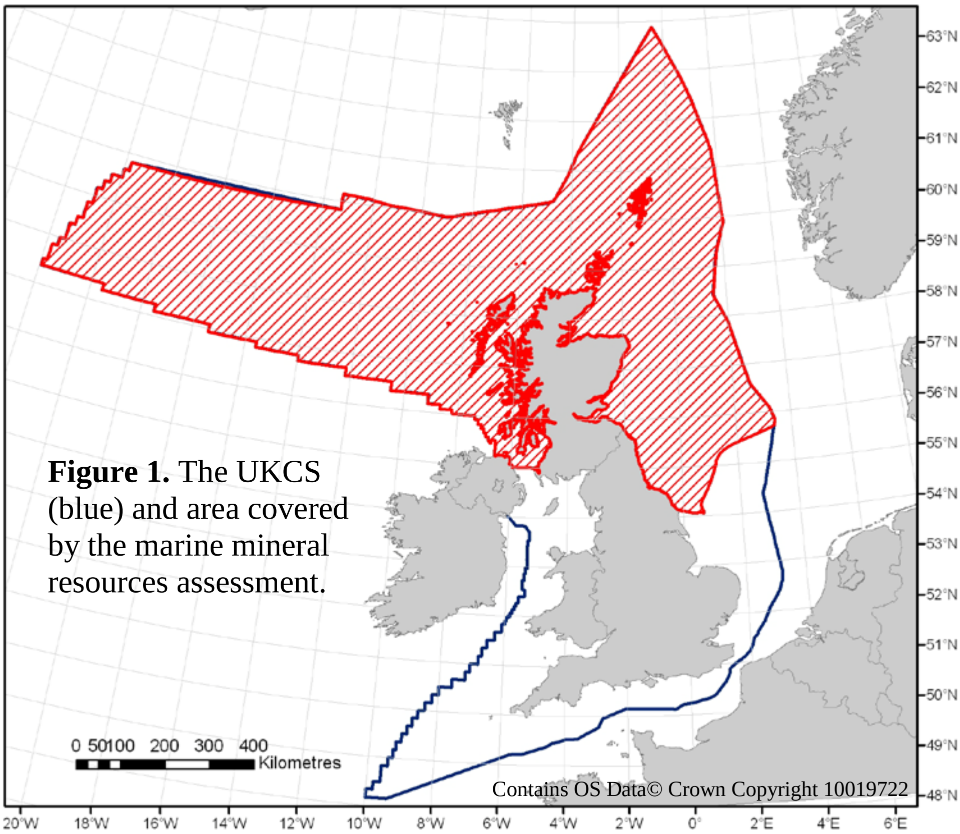

Figure 1. The UKCS (blue) and area covered by the marine mineral resources assessment.

The purpose of the map is to assist all interested parties involved in the preparation and review of marine plans, both in relation to the extraction of minerals and to the protection of mineral resources from sterilisation by development that prevents future mineral extraction. It provides a knowledge base, in a consistent format, on the nature and extent of mineral resources in the area. The primary objective is to provide baseline data which will assist long-term planning for minerals supply. However, it is anticipated that the map and report will also provide valuable background data for a much wider audience, including the minerals industry, other areas of planning, environmental and regulatory bodies and the general public.

2 What is a Mineral Resource?

A mineral resource is a natural concentration or occurrence of material of intrinsic economic interest in or on the Earth’s crust in such form, quality and quantity that there are reasonable prospects for eventual economic extraction.

Mineral resources generally correspond to the boundaries defined by geological mapping, which may be supplemented by more detailed geological data. The mineral resources defined by this study show the areas within which potentially workable minerals may occur. What may be of economic interest does change over time as markets decline or expand, product specifications change, recovery technology is improved or more competitive sources become available. The spatial extent of mineral resources therefore shows all minerals which have resource potential in terms of physical and/or chemical properties that make them suitable for specific uses, irrespective of the extent of the deposit, planning constraints (such as exclusion zones), operational constraints (such as water depth) and proximity to markets or other economic factors.

That part of a mineral resource which has been fully evaluated and is commercially viable to work is called a mineral reserve. In the context of marine planning, the term mineral reserve should strictly be further limited to those minerals for which a valid licence for extraction exists (i.e. permitted reserves). Without a valid planning consent no mineral working can take place and consequently the inherent economic value of the mineral resource cannot be released and resulting wealth created.

3 Marine Aggregate Mineral Resources

The UKCS contains a wide range of minerals. In terms of revenue generated and employment, sand and gravel for aggregate use makes a significant contribution to the UK economy. The UK is well endowed with marine aggregate resources and has one of the largest marine aggregate dredging industries in the world. These minerals make an important contribution to the supply of raw materials for both the construction sector and for coastal protection and reclamation (Highley *et al.*, 2007). Sand and gravel has a variety of construction applications including concreting aggregate, aggregates used in mortar, beach nourishment, material for coastal defences and fill applications. To date over 900 million tonnes of marine sands and gravels have been extracted from the UKCS (Selby, 2011). Marine aggregates account for around a third of the UK’s production of sand and gravel (Idoine *et al.*, 2012). In 2011, 19.12 million tonnes were extracted from UK waters (The Crown Estate, 2012).The principal minerals information presented on the marine sand and gravel resource maps is the geological distribution of all offshore aggregate minerals – differentiated between those areas containing aggregates suitable for construction or beach nourishment (considered to be resources of national importance) and those suitable for contract fill and land reclamation applications (considered to be resources of regional importance).

3.1 METHODOLOGY FOR ASSESSING MARINE AGGREGATE RESOURCES

Areas of aggregate mineral resource have been inferred using existing geological maps depicting Holocene and Pleistocene geological units. Where significant deposits (more than one metre thick) of granular, unlithified, sedimentary material are shown on the geological maps, the BGS's sea bed sample and core dataset have been used to ascribe aggregate properties. Further interpretation was undertaken using additional data, including bathymetry and geophysical information, in order to delineate the distribution of sand and gravel resources defined.

Marine sand and gravel resources have been categorised into resources considered to be of national importance and those that are only of regional importance. Nationally important aggregate resources are defined as being suitable for construction aggregate and beach recharge applications. They have been defined based on the geological suitability of sediments for aggregate applications, with reference to the relevant European Standards (principally BS EN 12620L:2002, Aggregates for Concrete). Nationally important resources meet the following criteria: deposits must be more than one metre thick with mud content of less than 10 per cent and a median grain size (D50) of over 0.25 millimetres. These have been further classified into fine aggregate and coarse aggregate using the lithic gravel content (lithic gravel is used to exclude biogenic carbonate, which is not considered suitable for aggregate resources). A D50 of 0.35 millimetres has been used as a threshold to further differentiate the fine aggregate fraction into coarse and fine sand. Coarse sand is of particular interest to the aggregates industry because it is an important component in concrete manufacture. A flow-sheet depicting the categorisation of aggregate resources can be seen in Figure 2.

Regionally important aggregate resources are defined as material suitable for contract fill and land reclamation applications. Regionally important resources have the following criteria: deposits must be more than one metre thick with mud content of less than 10 per cent and a median grain size of less than 0.25 millimetres.

Areas where the carbonate content of sand exceeds 50 per cent are also shown on this map. This is to highlight the large accumulations of biogenic material in some areas which have implications to the use of sediment for aggregate applications. High carbonate sands are limited to lower specification applications than those with high silica content. A limit of 50 per cent has been used as this defines the boundary between carbonate sediment and siliclastic sediment. There are no defined carbonate limits in European Standards for aggregate applications.

There are areas of the map where no resource has been inferred. At a regional scale and using data available to this study, there is no evidence for aggregate resources, although it is possible that some limited areas of resource may be present.

All mineral resources depicted on the marine sand and gravel resource maps are inferred resources. An inferred mineral deposit is that part of a mineral resource for which volumes and quality can only be estimated with a low level of confidence. These areas show the geological distribution of all offshore sand and gravel mineral resources. These resources are inferred from geological evidence and assumed, but not verified by geological continuity and are based on information gathered through appropriate techniques such as cores, sea bed sediment samples and shallow geophysics which can be limited or of uncertain quality and reliability.

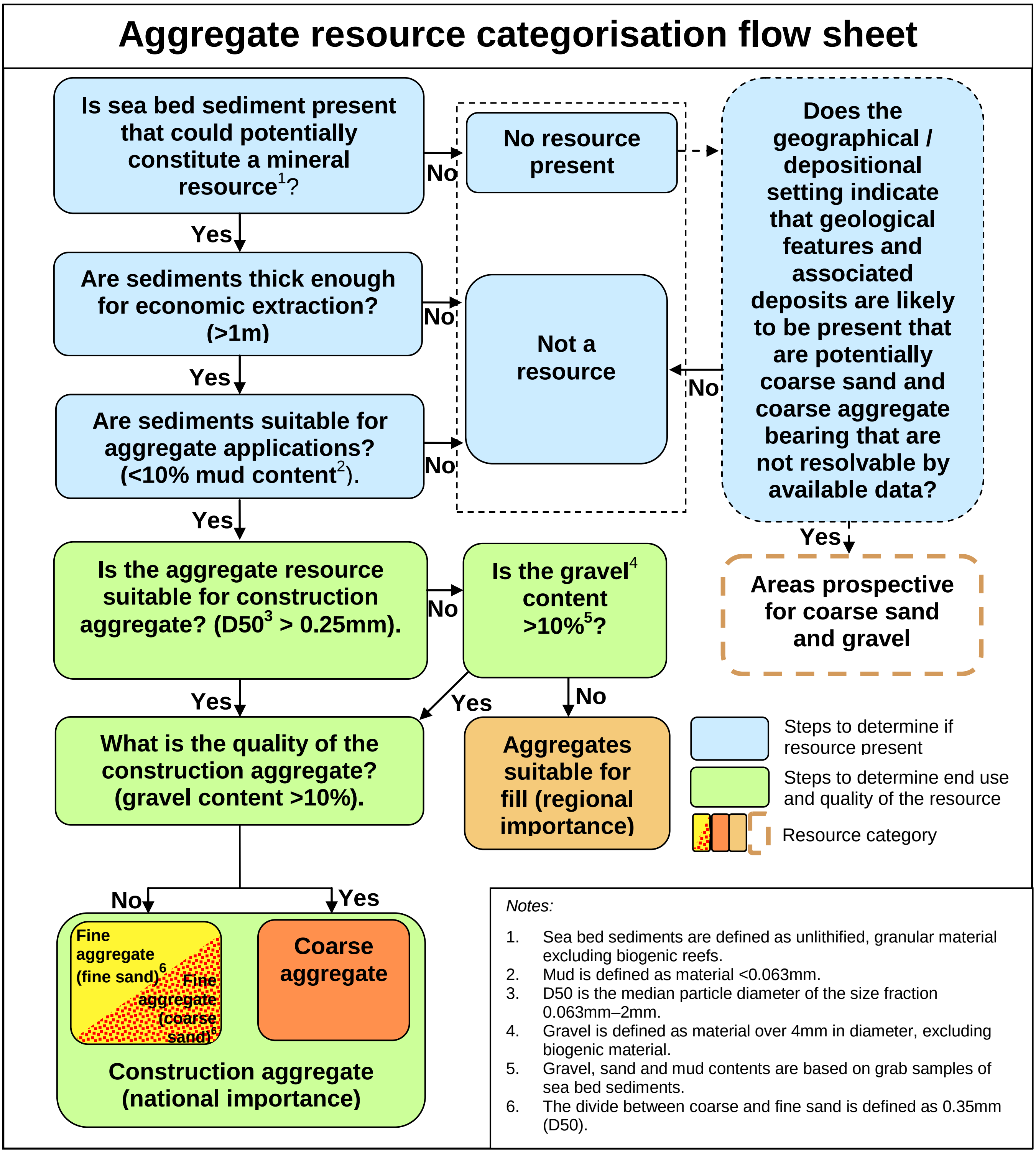

Figure 2. Aggregate resource categorisation flow sheet

3.2 REGIONAL REVIEW

The map coverage extends from Flamborough Head, covering the central North Sea throughout Scottish waters to the Mull of Galloway, including the waters around Northern Ireland. Major embayments include the Firths of Forth and Tay and the Moray Firth on the east coast and the Firth of Clyde in the west.

Generally the data coverage is sparse and therefore the reporting accuracy for many areas, especially in deeper waters, is limited. Confidence in the resource map is best in areas were data for thickness of superficial sediments exists (south of 55°N, around the Moray Firth and north of Shetland).

3.3 AGGREGATE RESOURCES OF SCOTTISH WATERS AND THE CENTRAL NORTH SEA

Sand and gravel deposits are accumulations of durable rock fragments and mineral grains which have been derived from the weathering and erosion of bedrock mainly by glacial and fluvial processes, but also by marine and wind erosion. The properties of gravel, and to a lesser extent sand, largely depend on the properties of the original bedrock from which they were derived. However, hydrodynamic processes are an effective mechanism for wearing away weaker particles, as well as separating different size fractions. Most economic sand and gravel is composed of particles that are durable and rich in silica (quartz, quartzite and flint). The marine sand and gravel resources of Scottish waters and the central North Sea area are shown in Figure 3.

Offshore sands and gravels have similar origins to their land-based equivalents and are mainly derived from glacial and fluvial depositional systems. Many marine aggregate resources are relict deposits that were formed during times when the sea level was much lower than present. During these periods large parts of the sea bed were exposed, glaciated or crossed by major river systems.

These types of relict sand and gravel deposits are found within Scottish waters and the central North Sea, which formed as glaciers advanced and subsequently retreated over the area. This has caused the deposition of thick glacial, periglacial and glacio-marine sediments. These glacial deposits comprise mainly very muddy sediments or till, capped with a thin coarse gravel lag, and are not considered prospective for sand and gravel. Occasionally however, glacial and glacio-marine sediments will form sands several metres thick underlain by clays. This type of resource is prevalent in the central North Sea but mud contents are typically high. This type of deposit may also be present in a north-east trending belt between the Isle of Lewis and Shetland where the veneer overlying till can be over 1m thick locally and comprise coarse sand and coarse aggregate. However, due to very limited data it has not been possible to delineated resources in this area.

Modern marine sand deposits (gravel is generally only mobilised by the most extreme sea bed currents in the modern marine environment) are formed by tidal currents and wave action reworking and sorting sand into semi-mobile banks and sand-waves. There are numerous sand-wave fields and sand banks in the map area, the largest of these are described below.

The sea bed sediments of Scottish waters and the central North Sea area are predominantly sandy material. Mud contents increase offshore in deeper water and in bathymetric deeps. Higher mud contents are recorded in estuarine areas such as the Firth of Forth due to fluvial input of terrestrial material. Muddy sediments may be derived from reworking of Quaternary tills and glaciomarine deposits (Fyfe *et al*., 1993). Gravelly sediments occur in localised patches in the eastern part of the area with more widespread areas associated with high current speeds and rocky platforms in the north and west.

High carbonate contents in sediments are recorded over the majority of the western shelf area, throughout coastal zones and on the shelf surrounding Orkney and Shetland. On the Orkney-Shetland platform, carbonate content of the sediment can be up to 100 per cent as a result of modern carbonate production and the presence of rocky substrates and strong currents (Farrow *et al*., 1984).

Geomorphological features such as sand waves and sand banks present potential accumulations of aggregate material. Sand waves occur through the area, both as isolated features and more extensive sand-wave fields. The dominance of sandy material across much of the central North Sea provides an abundance of mobile sediments to form such features. Sand-wave fields occur in localised areas in the outer Firth of Forth, with more extensive fields identified further north in the area surrounding the Aberdeen Bank. Large sand-wave features have also been identified 50 kilometres off north-east Scotland in water depths of 80 metres. These waves are up to 8 metres high and are likely to be relict features, formed during a period of lower sea level (Gatliff *et al*., 1994). The East Bank tidal sand ridges are also located at the southern boundary of the area. These north-east to south-west aligned moribund banks are up to 50 km long and 10 – 30 metres high (Gatliff *et al*., 1994).

High tidal velocities are recorded in the Moray Firth area, causing significant sediment transportation and reworking. There are also significant fluvial sediment inputs, up to 460 000 tonnes per year, with 50 per cent of this comprised of peat. Sand waves are recorded off Rattray Head, to the east of Orkney and in the Inner Moray Firth. There are also significant expanses of outcropping rock , with associated gravel patches to the south-east of Orkney, south of Fair Isle and off Tarbat Ness and Lossiemouth. 'Sandy Riddle'; an asymmetric sand bank is located at the eastern entrance to the Pentland Firth. This feature is 10 kilometres long and up to 60 metres high and is comprised of Holocene sandy gravels, although the core is likely to be glacial material. Sand waves and megaripples have been identified on the flanks. The bank has formed due to strong tidal currents in the Pentland Firth (up to 5.25 ms^{-1}) which decrease rapidly to the south-east. Complex eddy patterns have been recorded over the bank, maintaining the depositional conditions (Andrews *et al*., 1990)

In both the Firth of Forth and Moray Firth thick accumulations of sands are present with high mud contents. In the Firth of Forth mud contents are typically between 30-40 per cent at the surface, however this does decrease with depth. In the Moray Firth mud contents are less, between 10 and 20 per cent. In both these areas investigations have been conducted to assess the potential for these sediments for land reclamation and fill applications. Although as yet no sediment has been dredged they are prospective for low specification uses. As such an approximate outline of these areas have been displayed on an inset map on the main map face

In the northern North Sea, extensive sand-wave fields have been documented between Orkney and Shetland. There are also gravel waves to the south-east of Shetland, with maximum crest heights of 7.3 metres. West of Shetland and on the Hebrides shelf there are further examples of sand-wave fields and isolated waves. North of Orkney three large sand banks have been identified which are 10 km long, with heights of approximately 30 metres (Fyfe *et al*., 1993, Johnson *et al*., 1993). Sediments in these areas are often coarse due to the high current velocities.

The map produced for this area (Figure 3) shows that there may be extensive areas of aggregate suitable for fill in the eastern sections of the area, extending across the Marr Bank, and Swallow Hole. Further north and to the west, smaller isolated patches of aggregate suitable for fill have been identified. Resources found in the west are dominated by coarse aggregate.

Despite the model indicating widespread aggregate minerals in the Scottish waters and central North Sea area, it is difficult to quantify the accuracy of this data. Due to limited data availability, the model was constructed using a coarse grid at a lower resolution and limited information regarding sediment thickness than other areas of the UKCS. The model is therefore likely to overestimate the available resource due to extrapolation and the lack of data to define the extent of potential aggregate bearing areas. This is particularly relevant north of 55°N where no detailed thickness data was available. The area north of 62°N and the Rockall region in the far west were also largely discounted from the model due to lack of data, high water depths and muddy sediments. It is possible that resources may be present in areas identified as no resource due to the presence of local morainic and glaciofluvial features overlaying and incised into till that the data available to this study was not able to resolve.

There are two existing aggregate production areas in Scottish waters in the Firth of Forth (6 000 000 cubic metres over 10 years) and the Firth of Tay (66 000 cubic metres per year but has not been used for a number of years) (Scotland's National Marine Plan, Baxter *et al.*, 2011). The use of this material would be predominantly for land reclamation and fill applications as discussed above

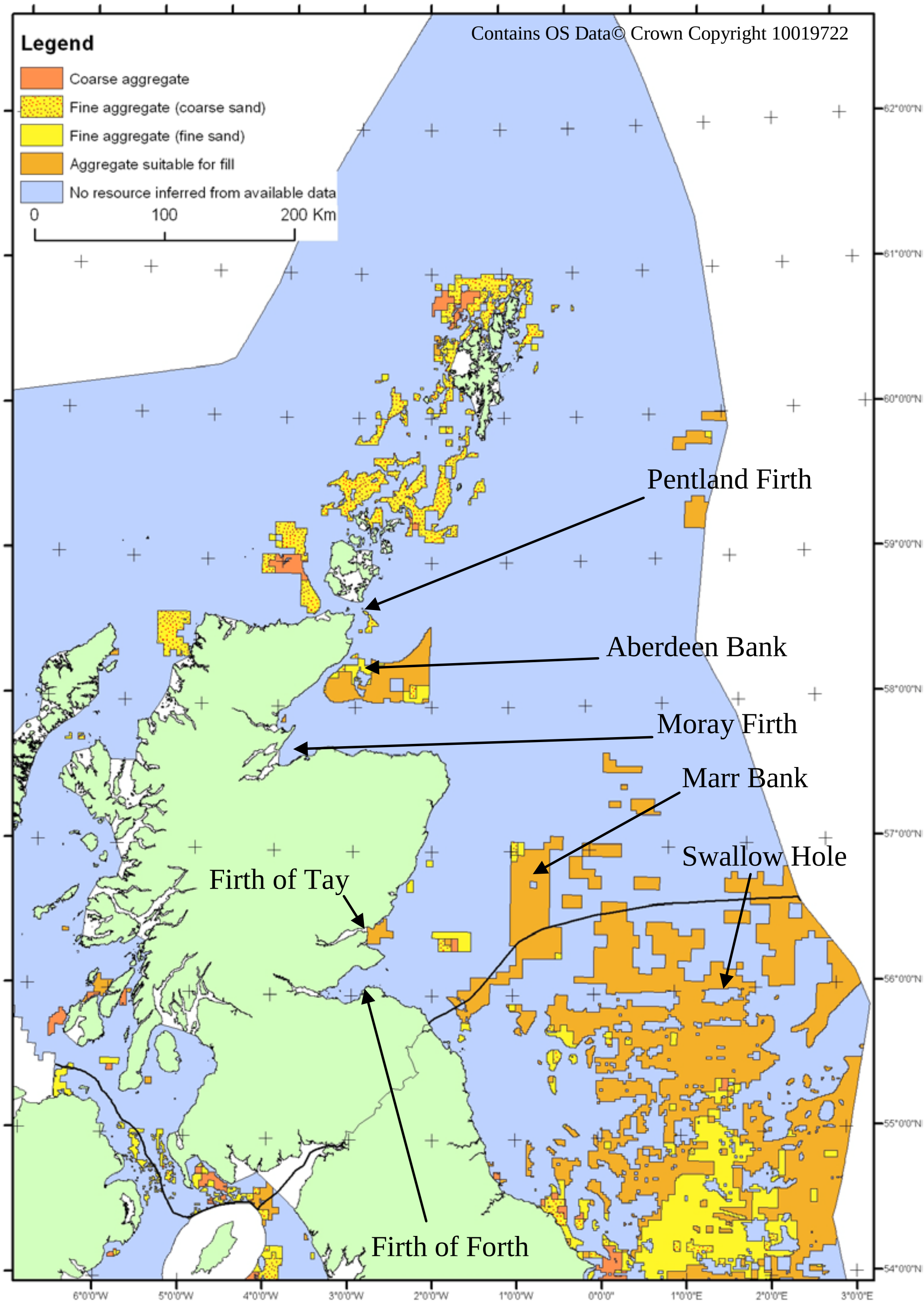

Figure 3. Sand and gravel resources of the Scottish waters and central North Sea area (full extent of map area not shown as no resource identified) (locations on the map are refferred to in the text)

4 Other minerals

Coal, evaporite and metallic mineral resources are located on or beneath the sea bed and these have been worked from onshore deep mines which extend for limited distances under the sea. Coal and evaporite minerals are an important national asset and adequate and steady supplies are needed to maintain current and future economic development. The UK metallic minerals industry has declined over recent years but substantial resources remain.

Coal and evaporite mineral resources have been inferred from geological mapping data and the interpretation of boreholes. These resources have not been evaluated on any systematic basis by drilling or by other sampling methods for the purpose of mineral exploration. The map depicting the distribution of geological formations hosting coal resources is included in Appendix 1 and the map depicting the extent of sub-sea evaporite-bearing geological formations (salt-bearing halite resources) is included in Appendix 2. Data on offshore metallic minerals is sparse and the location and properties of resources are poorly known. The presence of these resources is inferred from geochemical data, geological sampling and explorative actives by the extractive industry. The map depicting metallic mineral occurrences is included in Appendix 3.

4.1 COAL RESOURCES

Coal is a combustible carbonaceous sedimentary rock derived from lithified plant remains. It was formed by the alteration of dead plant material that initially formed as a superficial deposit of peat and has been buried by subsequent layers of younger sediments. As temperatures rose underground, due to increasing depth of burial, the initial superficial peat deposits were altered by the process of coalification forming first brown coals, including lignite and sub-bituminous coal, to black or hard coals that encompass bituminous coal, semi-anthracite and anthracite (Kendall *et al.,* 2010).

The process of coalification involves the loss of water and volatiles leading to an increase in carbon content, from about 60 per cent in peat to greater than 95 per cent in anthracite. The calorific value of coal also increases from about 15 megajoules per kilogram in peat, to about 35 megajoules per kilogram in bituminous coals and anthracite (Kendall *et al.,* 2010).

Coals are commonly defined by their content of moisture, volatiles, ash and fixed carbon. These properties together determine a coal’s rank, or degree of coalification. For example, anthracite is classed as a high rank coal whereas lignite is classed as low rank.

There are several sedimentary basins containing coal resources within this map area, the northernmost part of the Southern North Sea Basin, the mid North Sea Basin and the Forth Approaches Basin. These coal resources often occur near the sea bed and at depths below 1000 metres so in the past have been worked offshore from onshore shafts around the north- east coast of England and in the Firth of Forth.

The Southern North Sea Basin hosts extensive coal-bearing deposits of Late Carboniferous age. The majority of this basin is in the East Inshore and East Offshore map area however the northernmost part of the basin extends into the Scottish and central North Sea map area. Coal seams have been proved offshore between 2000 to 3000 metres below sea level and between 450-750 metres in thickness.

The Mid North Sea Basin, offshore east of Newcastle Upon Tyne, hosts coal deposits of Carboniferous age represented predominantly by the Caister Coal Formation. The onshore expression of these coal measures are represented by the Lower (Westphalian A) and Middle (Westphalian B) Carboniferous Coal Measures. Dinantian and Namurian aged coal units are also observed offshore in the Scremerston and Yoredale Formations. Within the Cleveland Basin the Caister Coal Formation occurs at a depth of approximately sea level to 1000 metres below sea level in the west, deepening to a maximum 2000 metres towards the east (BGS, 1999). Individual coal seams may reach three metres in thickness and constitute up to five per cent of the formation. The Caister Coal Formation has a maximum thickness of 750 metres (Cameron, 1993a). Data relating to the quality of Dinantian and Namurian coals is sparse; however, they are considered to be generally of low quality. The Scremerston Coal Formation has a total maximum thickness of about 266 metres; coal seams are typically about 1.5 metres thick and comprise less than five per cent of the total formation volume (Cameron, 1993a).

The Forth Approaches Basin contains Carboniferous aged coal-bearing strata, which are hosted by a series of synclinal structures. One of these structures is known to occur underneath the Firth of Forth where onshore coals are known to extend offshore. Coal seams range in thickness between three and nine metres; however, the thickness of individual seams can be variable due to synsedimentary faulting and folding (Gatliff *et al*., 1994). Within the Forth Approaches Basin Carboniferous coals occur at a depth of approximately sea level to 1000 metres below sea level at the edges of the coalfield, deepening to a maximum 2000 metres towards the centre (BGS, 1999).

Coals of Jurassic age are also present in central and northern North Sea. Typically these coals are thin and occur at significant depths (over 1500m). The highest concentrations of coals from Jurassic sediments occur around the Inner and Outer Moray Firth where coal seams are recorded in the Beatrice Formation, Brora Coal Formation and Pendland Formation. These occur at variable depths, between 1400-3600m, and are typically no greater then 1m thick, although seams up to 6m thick have been recorded in the Pentland Formation. These coals have not been shown on the map as they are much thinner and comprise much smaller proportions of the total formation then Carboniferous coal resources.

Where circumstances permit, certain coal seams may be a source for alternative fossil fuels. Sometimes known as 'unconventional hydrocarbons', alternative fossil fuels may present a viable replacement for natural gas. Obtaining alternative fossil fuels requires extraction technologies which are very different to those used to extract conventional hydrocarbons. Of relevance to offshore coal resources is methane recovered from undisturbed or ‘virgin’ coal seams (usually known as coalbed methane (CBM)) and underground coal gasification (UCG).

The prime requirements for CBM prospects are unworked coal seams thicker than 0.4 metres at depths of between 200 and 1200 metres. Low permeability and high drilling costs currently make deeper targets unattractive.

'Underground coal gasification' (UCG) involves combustion of underground coal seams *in situ* to produce synthetic gas (‘syngas’). Coals located at depths in excess of 1200 metres are considered unsuitable for Underground Coal Gasification (UCG), with ideal depths being between 600 and 1200 metres (Holloway *et al.*, 2005) Coal occurs at shallow depths, often below 1000 metres in this map area, there may be potential for both CBM and UCG in the future.

The potential to exploit offshore coal resources is uncertain. Any attempt to extract coal using conventional deep mining techniques from onshore would incur significant development costs given the depths and distances involved, therefore conventional extraction is currently unlikely. Likewise, it is unlikely that offshore coal resources will be exploited more than a few kilometres from shore by any of the above new technologies (CBM and UCG) in the near future. Research is required to obtain a better indication of their potential. Further information on the UK’s coal resources can be found in the BGS Mineral Planning Factsheet on coal

(http://www.bgs.ac.uk/downloads/start.cfm?id=1354).

4.2 EVAPORITE RESOURCES

Evaporite minerals, including gypsum and anhydrite, halite (rock salt) and, more rarely, potash and magnesium salts, are precipitated during the evaporation of seawater. The arid conditions that existed during Permian and Triassic times across Britain resulted in several cycles of evaporite deposition, represented by numerous halite sequences. These resources have the potential to be extracted at depth via brine pumping, and the resulting cavities have potential for underground gas storage.

There are several basins in the map area which host evaporite deposits are present in this map area; The Southern, Central and Northern North Sea Basins, the Moray Firth Basin, the Forth Approaches Basin and North Channel Basin. In the deeper parts of these basins, the salt is prone to halokinesis causing it to migrate and be concentrated in salt domes. The northernmost extent of the Southern North Sea Basin is within this map area; however the majority of the mineral resource lies within the East Inshore and East Offshore Map (Bide *et al*., 2011). The most significant evaporite formations in the Southern North Sea Basin are the Billingham Anhydrite Formation and the overlying Boulby Halite Formation which, along with the Boulby Potash Member, are known offshore as the Leine Halite.

The Central North Sea Basin, Northern North Sea Basin, Moray Firth Basin and Forth Approaches Basin consist of the Upper Permian evaporite deposits of the Zechstein Group. The most significant evaporite formations are the Shearwater Salt Formation and the Halibut Anhydrite Formation. The Shearwater Salt Formation includes the thick Upper Permian evaporites that occur across the centre of the Northern Permian Basin. The formation is dominated by halite but includes significant components of sulphate minerals (particularly anhydrite and polyhalite) and chlorides (sylvite and carnallite). These minerals are concentrated into discrete intervals in some places which vary from a few metres to several tens of metres thick. However, these intervals, cannot be correlated between boreholes due to the regional halokinetic deformation.

Few wells have drilled to the base of the Shearwater Salt Formation but of those that have, the maximum thickness recorded is 2142 metres and in most other wells the thickness is between 500 and 1000 metres (Cameron, 1993b). The Upper Permian Halibut Anhydrite Formation occurs below the Shearwater Salt Formation. It is predominantly anhydrite but contains an argillaceous unit and local developments of carbonate. Thicknesses vary but it is generally between 20 and 120 metres thick throughout the Northern Permian Basin (Cameron, 1993b). Evaporite units from within the North Channel Basin have been identified by boreholes but their extents and properties are poorly constrained.

Although there are extensive offshore evaporite resources on the UKCS, their extraction may not always be economically viable. Feasibility of mining these resources depends on factors such as the commodity prices, geology, available technology, depth of deposits, distance to shore and other factors.

Further information on the UK’s salt resources can be found in the BGS Mineral Planning Factsheet on salt (http://www.bgs.ac.uk/downloads/start.cfm?id=1368).

4.3 METALLIC MINERALS

Marine processes can lead to the concentration of metallic minerals in sea bed sediments. Currently there are no workings on the UKCS for metallic minerals. However, several types of mineral have been recorded in potentially economic concentrations and the working of some deposits has been considered in the past.

One of the most common types of metallic marine mineral resources are dense (or ‘heavy’) minerals such as cassiterite and zircon. These are commonly concentrated in placer-type deposits. The formation of placer deposits is fundamentally a process of sorting heavy minerals from those of a lower density during sediment deposition.

In marine environments, chemical precipitation is also an important potential process in concentrating certain metals. For example, manganese nodules form by the precipitation from sea water of an array of metals, such as manganese, nickel, copper, molybdenum and cobalt. The processes by which manganese nodules form are numerous and complex, and may include bacterial oxidation, authigenic reactions during sedimentation, and direct precipitation on to a suitable substrate (Robb, 2005).

Titanium (rutile; ilmenite)

Significant accumulations of rutile and ilmenite are not known on the UKCS. However, where heavy-mineral sands have been indentified offshore, for example offshore areas of north-east Scotland and the Sea of the Hebrides, it is likely these sediments will also contain titanium minerals such as rutile and ilmenite (Colman, 1994).

Zircon

The majority of zircon occurrences are confined to onshore beach sands or shallow near -shore sands. Sea bed exposures of Tertiary sediments in the north-western North Sea have yielded elevated concentrations of zircon; sediments offshore from Alnmouth, Northumbria, and sediments on the Dogger Bank have zircon concentrations of 0.043 per cent and 0.1 per cent respectively (Hardisty, 1990).

Other heavy minerals (chromite; magnetite; haematite; garnet; olivine)

Placer-type deposits of heavy minerals are known to occur in the vicinity of Shetland, where they are restricted to the near-shore areas off Unst on the eastern side, and in St Magnus Bay to the west. Heavy minerals comprise up to 5 per cent of the total fine-sand fraction and consist mostly of garnet, haematite, magnetite, and chromite (Stoker *et al*., 1993). The mineral assemblage comprises about 20-50 per cent garnet; about 10-20 per cent magnetite; up to 15 per cent chromite; and about five per cent staurolite (Johnson *et al*., 1993). In the vicinity of the eastern Outer Hebrides, high concentrations of heavy minerals are known to occur in the near shore of The Minch. High concentrations of these minerals may also exist in the near shore west of the Outer Hebrides (Stoker *et al*., 1993).

Sediments from Loch Scridain, Mull, and the Sea of the Hebrides have yielded magnetite concentrations between 1-2 per cent; however, in exceptional cases samples containing about 5.6 per cent magnetite have been collected (Fyfe *et al*., 1993).

Marine sands offshore Rum and south-west Skye contain considerable quantities of olivine and chromite, probably derived from the Tertiary igneous complexes of Rum and the Cullins of Skye. The upper metre of sand in submerged deltaic areas south of Rum contains approximately 70 000 tonnes of chrome spinel with an average Cr_2O_3 content of 32 per cent. Approximately 1.5-2 million tonnes of forsterite-rich olivine is also present with an average MgO content of 47 per cent. Other minerals likely to be present in the sediments are ilmenite and vanadiferous magnetite (Gallagher *et al*., 1989).

Manganese nodules

Manganese nodules are known to occur in small patches in many of the sea lochs around the Firth of Clyde, for example Lochs Fyne, Goil, and Striven (Evans, 1986). In Loch Fyne the nodules are confined to the upper 10-15 centimetres of surface sediments in water depths of about 180-200 metres. The nodules are spherical and range from a few millimetres to about three centimetres in diameter. The nodules contain about 30 per cent manganese and four per cent iron; barium, cobalt, molybdenum, nickel and zinc are also variably concentrated in the nodules (Calvert and Price, 1970).

Manganese carbonate concretions also occur in the surface sediments of Loch Fyne. The concretions are irregularly shaped and are typically between 0.5-8 centimetres in size. They have lower concentrations of both manganese and iron, about 19 and 1.5 per cent respectively, but are typically more widespread (Calvert and Price, 1970).

5 Limitations

The purpose of the maps described in this report is to show the broad distribution of mineral resources present in Scottish waters and the central North Sea area, based on the available data. They delineate areas within which potentially workable minerals may occur. These areas are not of uniform or equal potential and also take no account of planning constraints that may limit their working. The economic potential of individual sites can only be proved by a detailed evaluation programme. Such an investigation is also an essential precursor to the submission of a planning application for mineral working.

With reference to the marine aggregates map, extensive areas are shown as having no mineral resource potential, although some aggregate dredging may occur in these areas. Dredging operations generally reflect local or specific situations that are not resolved by the density of data that is available for compilation of this regional-scale map and require site-specific investigation to identify. Marine mineral licences may therefore be located in areas where no resource is shown. It is also possible that local variations in geology that are too detailed to be resolved by this regional-scale survey can contain substantial volumes of resource and could prove to be significant future resources.

Glossary

Aggregate:	Particles of rock which, when brought together in a bound or unbound condition, form part or whole of a building or civil engineering structure.
Biogenic:	A material formed by organisms or biological activity.
Carboniferous:	A period of geological time from 359 to 318 million years ago.
Clast:	A rock fragment; commonly applied to a fragment of pre-existing rock included in a younger sediment.
Evaporite:	A mineral formed from precipitation from concentrated brine.
Flint:	Variety of chert occurring in the Chalk of northern Europe.
Fluvial:	Relating to a river; a deposit produced by the action of a river.
Glaciofluvial:	May be applied to sediment transported and deposited by running water discharged from an ice mass.
Glacial deposits:	Heterogeneous material transported by glaciers or icebergs and deposited directly on land or in the sea. Often poorly sorted.
Gravel:	Granular material in clasts between 4 and 80 millimetres; coarse aggregate. Used for general and concrete applications.
Holocene:	The youngest epoch of the Quaternary period from 0.01 million years to present.
Mineral:	A naturally formed chemical element or compound and normally having a characteristic crystal form and a distinct composition.
Moraine:	A landform deposited directly by a glacier.
Permian:	A period of geological time from 299 to 251 million years ago.
Placer:	A deposit of economic minerals formed by natural (often gravity driven) processes).
Periglacial:	Cold, dry climatic conditions occurring away from glacial ice.
Pleistocene:	An epoch of the Quaternary period from 2.58 to 0.01 million years ago.
Quartz:	Crystalline silica; an important durable rock-forming mineral.
Quaternary:	An era of geological time from 2.58 million years ago to present.
Reserve:	That part of a mineral resource that is economical to work and has been fully evaluated on a systematic basis by drilling and sampling and is free from legal or other obstruction that might inhibit extraction.
Resource:	Natural accumulations of minerals, or bodies of rock, that are, or may become, of potential economic interest as a basis for the extraction of a commodity.
Sand:	A granular material that is finer than 4 mm, but coarser than 0.063 mm.
Sandstone:	A sedimentary rock made of abundant fragments of sand size set in a fine-grained matrix or cementing material. The sand particles are usually of quartz.
Siliclastic:	a clastic sediment predominantly (over 50%) composed of silicate minerals

Till: glacial sediments, often unsorted clay and boulders deposited directly from glaciers.

Triassic: A Period of geological time from 250 to 200 million years ago.

Westphalian: A Period of geological time during the late Carboniferous.

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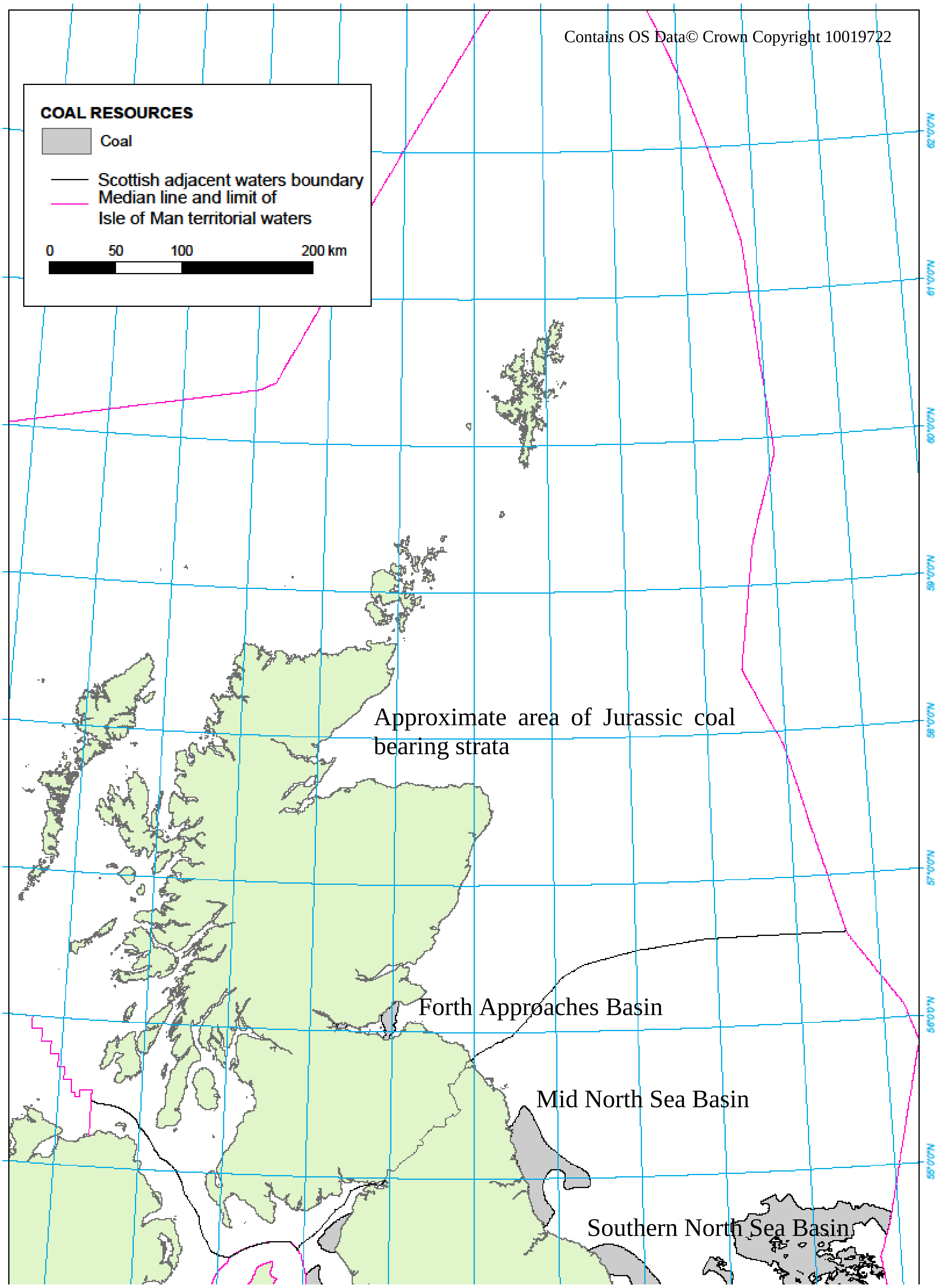
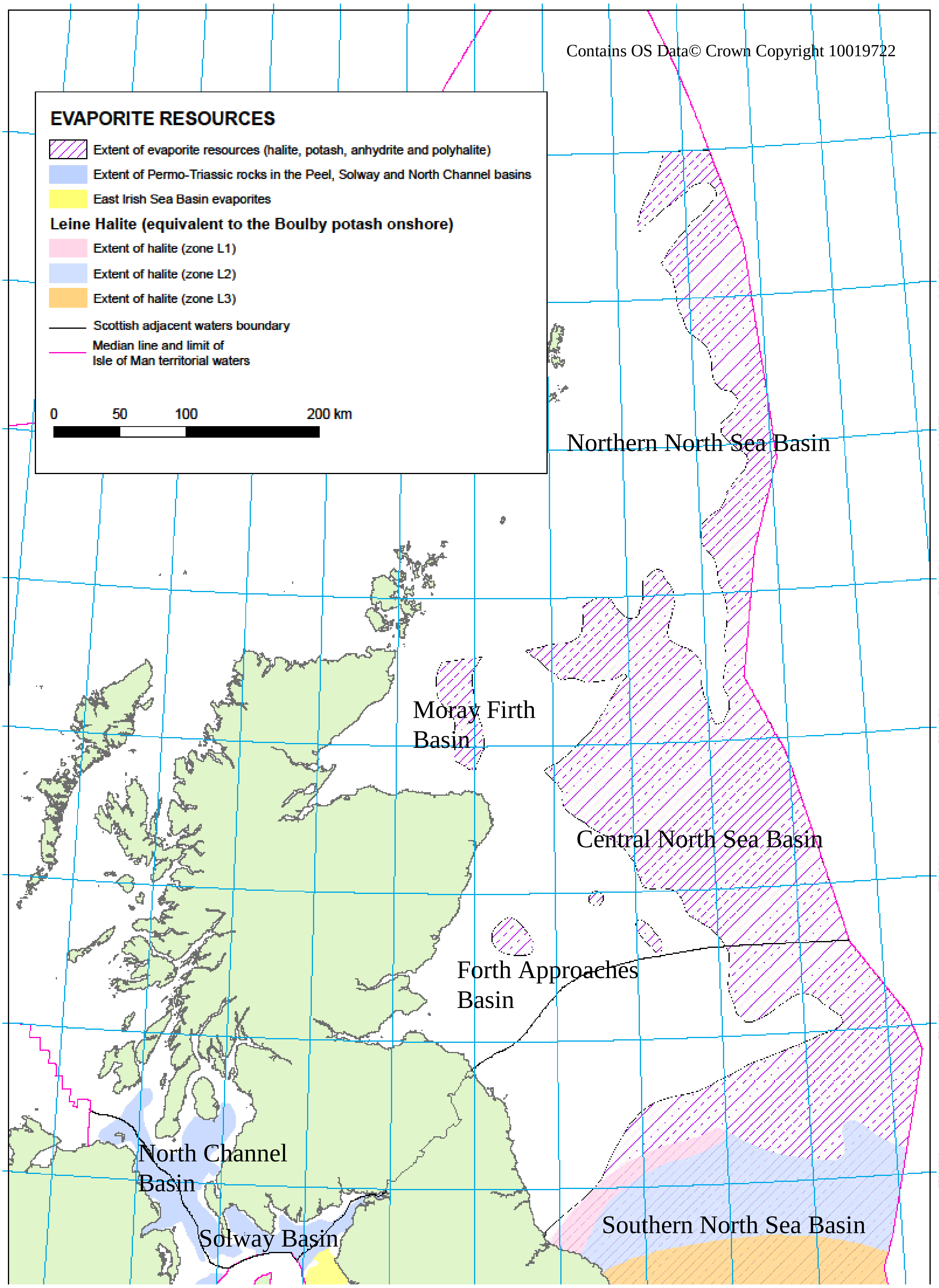
Appendix 1 Map of coal resources



Appendix 2 Map of evaporite resources



Appendix 3   Map of metallic mineral occurences