British Geological Survey
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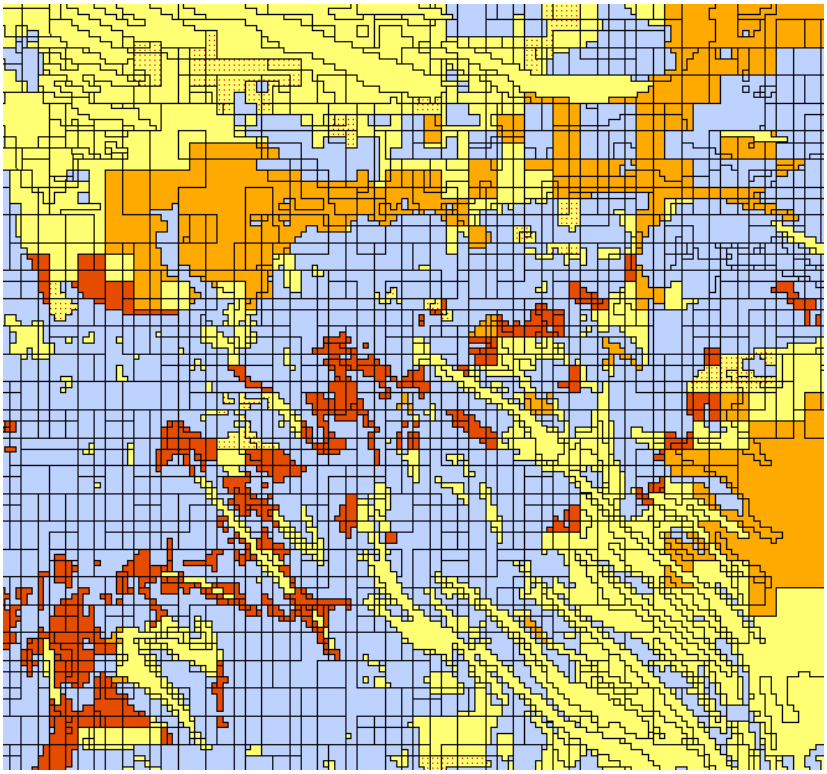
The Marine Mineral Resources of the UK Continental Shelf: Final Report

Minerals and Waste Programme

Commissioned Report

CR/13/020N



BRITISH GEOLOGICAL SURVEY

MINERALS AND WASTE PROGRAMME

COMMISSIONED REPORT CR/13/020N

The Marine Mineral Resources of the UK Continental Shelf: Final Report

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The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as basic research projects. It also undertakes programmes of technical aid in geology in developing countries.

The British Geological Survey is a component body of the Natural Environment Research Council.

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Forward

In 2011, The Crown Estate commissioned the British Geological Survey (BGS) to begin a two year research project to undertake a *Mineral Resource Assessment of the UK Continental Shelf* with the results being depicted as a series of maps, accompanying reports and associated GIS data. This report details the process behind the compilation of these maps. It outlines the data sources used in the project, the methodology used to compile the data, the confidence in the data and any caveats associated with the data and its use. This report focuses on the national model for sand and gravel, where relevant information on the data for other minerals is included for completeness.

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 marine 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.

Acknowledgements

The authors would like to thank Ian Selby (The Crown Estate) and members of the dredging industry for their help in reviewing and providing advice for this study as well as BGS staff Paul Henni, Rob Cooke, Caroline Adkin, Eileen Gillespie, Kathrine Linley and Anne Richardson for their help with the management of data compiled for this project.

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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.

To improve the knowledge base on the UK's offshore mineral resources The British Geological Survey (BGS) undertook a commission from The Crown Estate to prepare a series of mineral resource maps and data which cover the UKCS. This mineral resource information was compiled following a desk study of data held by the BGS and external sources. The methodology involved modelling data in a GIS environment to integrate the multiple data sources and utilising expert knowledge to interpret and assess the results.

Mineral resource maps

The UKCS contains a wide range of minerals –aggregates (sand and gravel) evaporite minerals (such as potash), coal and metallic minerals. Excluding gas (which did not form part of this study) the most important of these in terms of revenue generated and employment, is sand and gravel for aggregate use. For this reason the maps produced by this study depict the locations of sand and gravel resources and information regarding other minerals can be found in the reports which accompany the maps and associated GIS data. The purpose of the maps and data produced by this study is to assist all interested parties involved in the preparation and review of marine plans. This is both in relation to the extraction of minerals and to the protection of mineral resources from sterilisation by development or planning constraints that may prevent future mineral extraction. The maps and data provide a knowledge base, in a consistent format, on the nature and extent of mineral resources for the UKCS. The primary objective is to provide baseline data which will assist long-term planning for minerals supply. However, it is anticipated that this information 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.

A total of four maps (at a 1:500 000 scale) and accompanying reports have been produced, the associated digital data for sand and gravel is at a 1:250 000 scale (Figure 1). The references for these are cited below:

BIDE, T. P., BALSON, P. S., MANKELOW J. M., SHAW R. A., WALTERS A. S., GREEN, S. AND CAMPBELL, E. 2012. The Mineral Resources of the East Inshore and East Offshore Marine Plan Areas, Southern North Sea. *British Geological Survey Open Report*. OR/12/095. 23pp.

BIDE, T. P., BALSON, P. S., CAMPBELL, E., AND GREEN, S. 2012. Marine sand and gravel resources of the East Onshore and East Offshore Marine Plan Areas. *British Geological Survey Open Report* OR/11/049. Map at 1:500 000 scale.

BIDE, T. P., BALSON, P. S., MANKELOW J. M., SHAW R. A., WALTERS A. S. AND CAMPBELL, E. 2012. The Mineral Resources of the English Channel and Thames Estuary. *British Geological Survey Open Report.* OR/12/096. 28pp.

BIDE, T. P., BALSON, P. S., AND CAMPBELL, E. 2013. Marine sand and gravel resources of the English Channel and Thames Estuary. *British Geological Survey Open* Report OR/11/66. Map at 1:500 000 scale.

BIDE, T. P., BALSON, P. S., MANKELOW J. M., SHAW R. A., WALTERS A. S. AND CAMPBELL, E. 2012. The Mineral Resources of Welsh Waters and the Irish Sea. *British Geological Survey Open Report*. OR/12/097. 26pp

BIDE, T. P., BALSON, P. S., AND CAMPBELL, E. 2013. Marine sand and gravel resources of Welsh waters and the Irish Sea. *British Geological Survey Open Report* OR/12/065. Map at 1:500 000 scale.

GREEN, S., BIDE, T. P., CAMPBELL, E., BALSON, P. S. MANKELOW J. M., SHAW R. A. AND WALTERS A. S. 2013. The mineral resources of Scottish Waters and the Central North Sea. *British Geological Survey* Open Report. OR/13/013

GREEN, S., CAMPBELL, E., BIDE, T. P., AND BALSON, P. S. 2013. Marine sand and gravel resources of Scottish Waters and the Central North Sea. *British Geological Survey Open Report*, OR/13/012. Map at 1:500 000 scale.

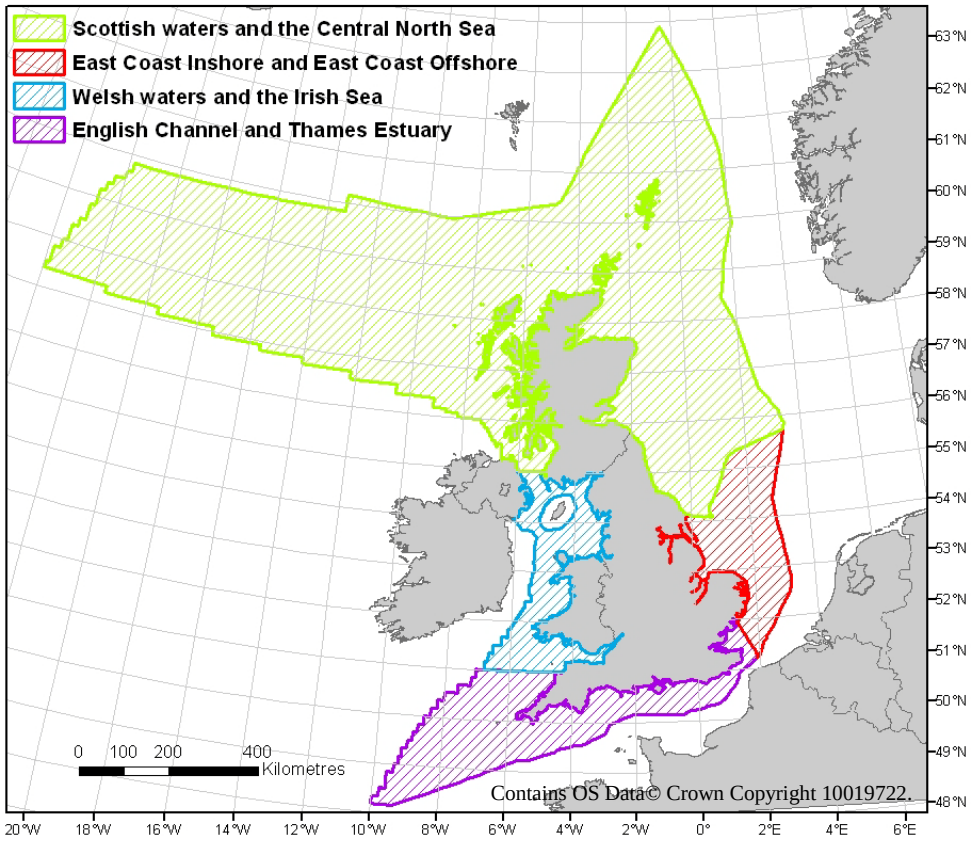

Figure 1: Map areas covered by the marine mineral resource maps

Each map is accompanied by a digital GIS dataset. This has been supplied to The Crown Estate in ESRI Arc GIS format and consists of 10 individual files which contain information on all mineral resources and all data depicted on the paper maps.

Resource block summaries

To provide further information regarding specific areas containing significant sand and gravel resources resource blocks have been defined around England and Wales. The purpose of these is to focus on specific areas of particular interest to the aggregates industry and give an indication of the type, qualities and volumes of resources present based on data from the UK marine sand and gravel map and geological interpretation. This information is contained within a separate report:

BIDE, T. P., BALSON, P. S. AND GREEN, S. 2012. Resource block summaries for England and Wales. *British Geological Survey Commissioned Report*, CR/12/147. 17pp.

A total of 13 resource blocks have been defined, these cover areas of high potential for marine sand and gravel resources and consist of; six blocks for the east coast, covering the Dogger Bank

to the Outer Thanes Estuary; three blocks for the English Channel covering the Solent area, East English Channel and Thames Estuary and a further four blocks around the coast of Wales and off the North West of England. Areas of limited aggregate potential have not been covered in detail but further information regarding the geology and resources present in these areas can be found in the summary reports which accompany the relevant marine aggregate map.

Safeguarding offshore minerals

To provide specific information on how this information may impact and influence planning in the marine environment a separate, report was produced

WRIGHTON, C. E., BIDE, T. P. AND MANKELOW, J. M. 2011. Safeguarding options for marine mineral resources. *British Geological Survey Open Report*, OR/11/056. 23pp.

This report addresses the issue of ensuring that natural mineral resources are not unnecessarily sterilised by other forms of development which can be achieved via the process of mineral safeguarding. The report outlines the possible options for minerals safeguarding in the marine environment.

1.1 OTHER MINERALS

This report details the process of identifying sand and gravel mineral resources and the creation of the marine aggregate map for the UKCS. In addition data for 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. Data on offshore metallic minerals is sparse and the location and properties of resources are poorly constrained. The presence of these resources is inferred from geochemical data, geological sampling and explorative actives by the extractive industry. Further information regarding these mineral types is located in the relevant map summary reports.

2 Data Sources

BGS holds a significant quantity of marine data acquired on behalf of the National Environmental Research Council (NERC), their partners, other non-commercial organisations and commercial companies. These data have been collected since the 1960s, and are therefore in a variety of formats, including paper records, analogue media and digital data. Much work has been done to condition and store these data in appropriate systems, with a view to increasing accessibility and usability of the legacy data.

Due to the desk-based nature of this study it was important that the most up-to-date and comprehensive sources of data were used. Due to the national extent of this study, data sources with seamless national or regional coverage were of most use but data sources with more limited coverage were also used for many areas were available. Principal data sources used were from:

- BGS's legacy dataset of sea bed sediment samples, cores, geophysical records and offshore geological mapping (previously published as a series of 1:250 000 scale geological maps covering sea bed sediments, Quaternary geology and bedrock geology, see section 2.1).
- Data collected as part of Marine Aggregates Levy Sustainability Fund (MALSF) work, principally from the Regional Environmental Characterisation (REC) reports.
- Bathymetric information supplied under licence to BGS by The Crown Estate.
- Previous work on marine sand and gravel resources commissioned by the Crown Estate.
- Limited amounts of data provided by the dredging industry.

Due to time constraints on this study the very significant volumes of data that have been collected as part of exploration activity by the marine aggregate dredging industry were not used on a systematic basis for this study. The coverage of these data is incomplete and coverage is concentrated in areas of existing licences, where, in terms of planning consideration of resources may be less important as a licence has been granted and sterilisation of resource is therefore unlikely. However, where appropriate, for areas which are not covered by other data sources especially in areas with potential for aggregate resources limited amounts of industry data have been used.

Data sources were divided into two principal types, those with national or near national coverage that would be included in the GIS model that this study used to define sand and gravel resources and those that would be used to truth and add value through geological interpretation of the model outputs.

This section outlines the main sources of information that have been of used by the aggregate resources assessment of the UKCS. Data collected and owned by BGS, plus data collected and owned by third party organisations, but available for use for this study, are described.

2.1 DATA HELD BY BGS

2.1.1 Sample Data

BGS hold a large amount of data relating to offshore sampling activities spanning several decades. There are currently over 89 500 unique sample stations with almost complete coverage (at varying densities) across the UKCS, as shown in Figure 2.

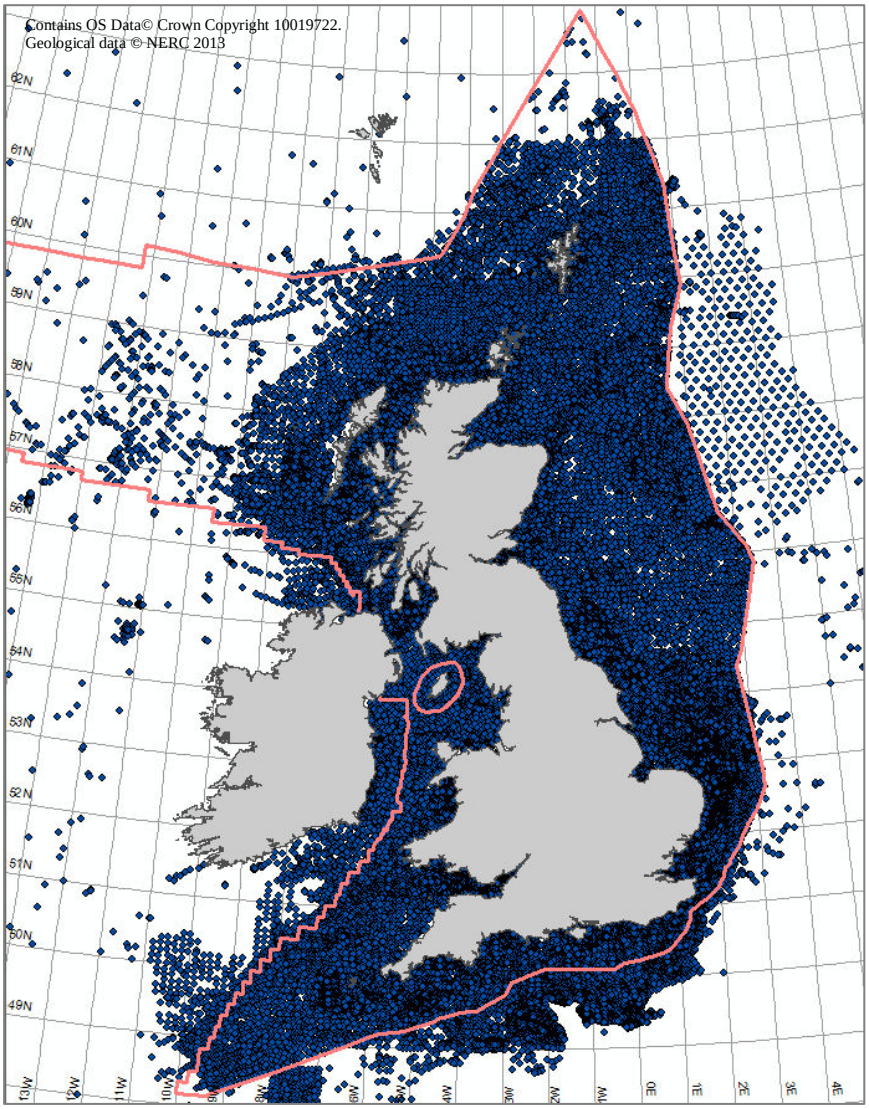

Figure 2: Sample station coverage held by BGS for the UKCS and adjacent areas

Potentially, multiple activities are carried out at each sample station, these activities include photography and video footage of the sea bed, sampling of the sea bed (via grabbing or dredging) and sampling of the sub surface (via coring and drilling). Physical samples are then subject to a wide range of observation and analysis such as:

- summary geological description (including down hole interval observations)
- gravel, sand and mud content based on the Wentworth Scale (Wentworth, 1922)
- carbonate content for gravel, sand and mud fractions
- Folk classification (Folk, 1954)
- particle size distribution (predominantly either phi or half phi intervals)
- geotechnical and geochemical analysis

As can be expected with such a large dataset spanning 45 years, there are inconsistencies within the data. The coverage, quality and types of data collected varies from area to area, for example early work often does not contain a particle size breakdown or carbonate analyses of each fraction. In general, coverage of this dataset is very good nationally, but significant gaps do exist for areas around western Scotland, and sample points are often sparsely placed far offshore.

The most relevant information collected at offshore sample stations with regards to aggregate resources is that relating to sand, gravel and mud content (including carbonate content of the

individual fractions), plus the particle size distribution. Of the 89 500 offshore sample stations, approximately 32 750 sample sites have information on sand, gravel and mud content, with nearly 25 800 having the particle size breakdown, as shown in Figure 3.

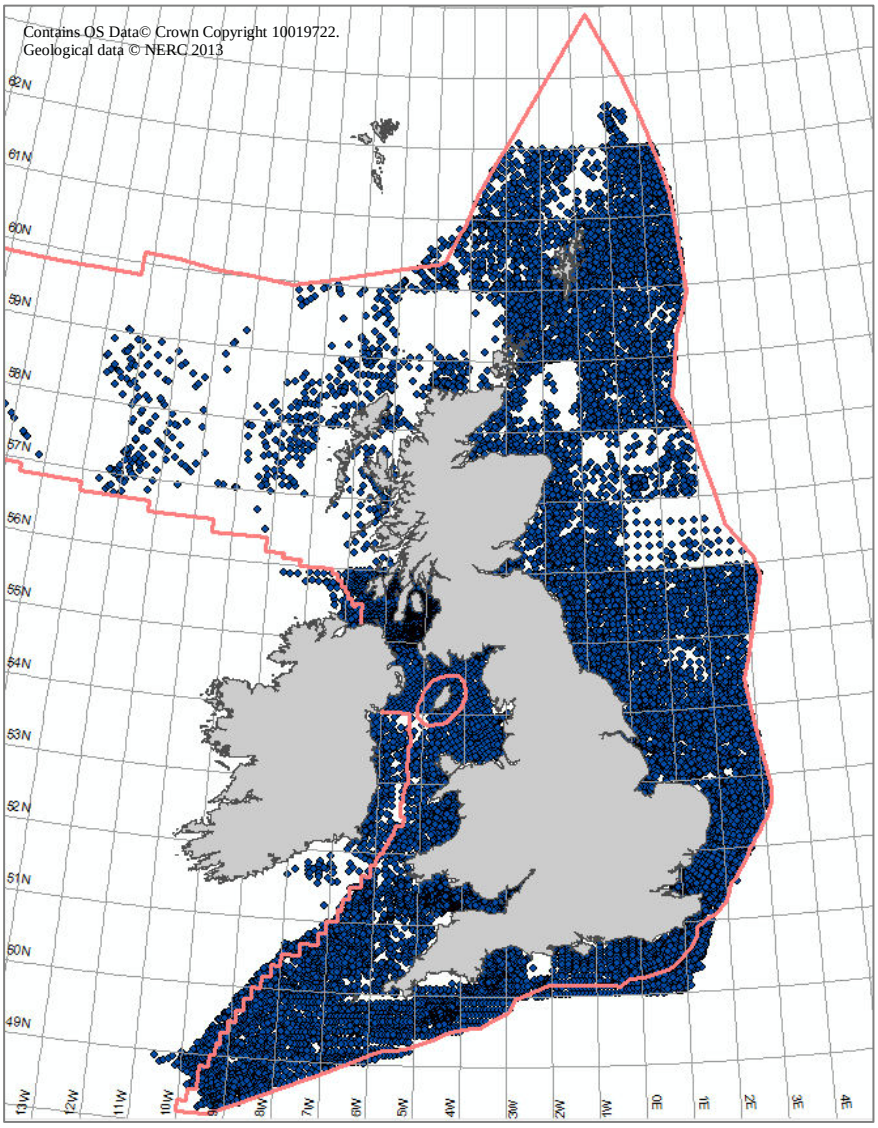

Figure 3: Sample stations with particle size values held by BGS for the UKCS

The most valuable data for aggregate resource studies are particle size distribution, as statistical indicators relating to the mean grain size or sorting of the sediment can be derived from these. The format of particle size data held by BGS varies a great deal, but they are most commonly in phi or half phi intervals. For some earlier surveys (for example those in the Lake District and Liverpool Bay areas) different sieve meshes have been used. The maximum and minimum sieve sizes used also vary considerably depending on the aims of the survey. The vast majority of samples were sieved only between -1 phi (2 mm) and 4 phi (63 µm) corresponding to the sand fraction of the Wentworth Scale (Wentworth 1922).

One of the most limiting factors, when using these data to consider marine aggregate resources, is that sediment grain size is categorised to the Wentworth Scale, which defines gravel as over 2 mm (-1 phi). However, gravel is defined by particles over 4 mm (-2 phi) by the aggregate industry and in European Standards. In the aggregate resources assessment of the UKCS, for samples where no data exists for sieves over 2 mm, statistical methods (section 3.8) were used to interpolate the quantity of material in the gravel fraction according to the European Standard.

Sample data have been used to underpin the marine aggregate resource map, being used to attribute areas of sediment with aggregate properties. This dataset was of great use due to its extensive coverage, in the areas where data are not available areas have either been left as blank

(in the case of data non-essential for resource categorisation, section 3.5) such as carbonate content of sand) or values have been interpreted from other data sources.

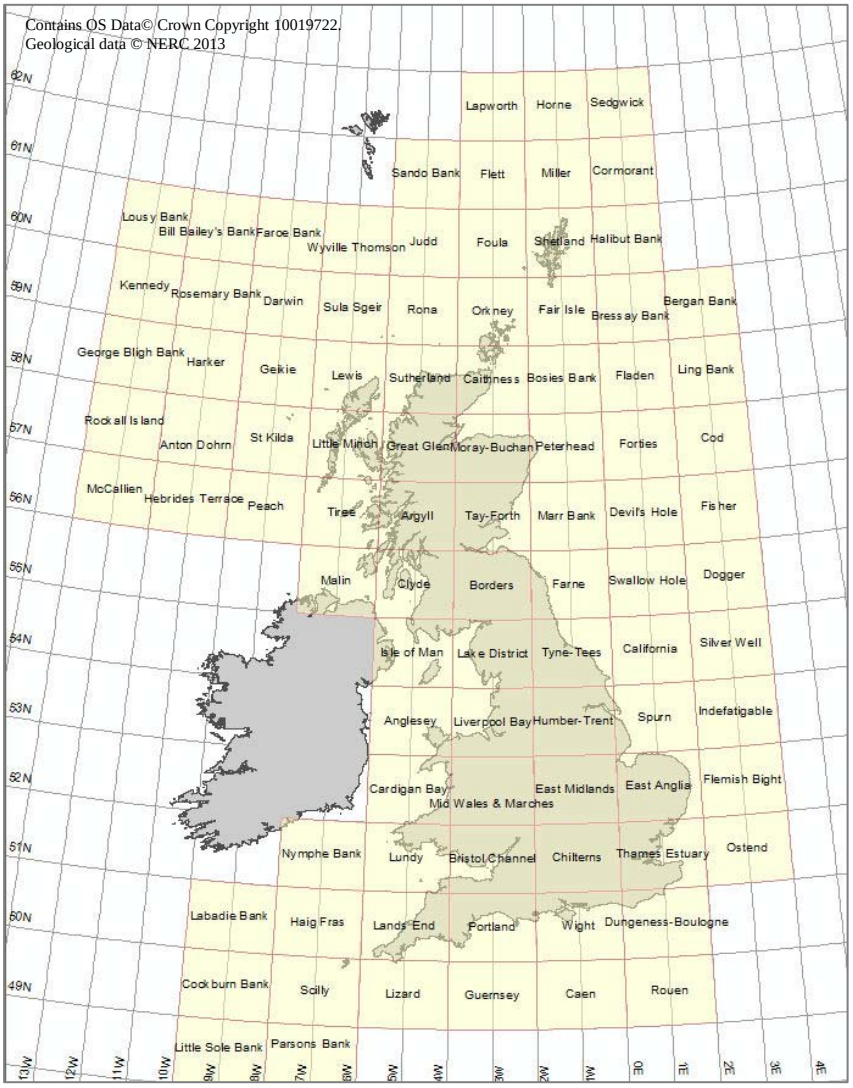

Figure 4: BGS 1:250 000 map sheets covering the UKCS (note that not all map sheet areas contain published data)

2.1.2 Geological Maps

Maps in the 1:250 000 Geological Maps (UTM Series) show three types of geological information: solid (bedrock) geology, Quaternary (drift) geology or sea bed sediments. These are usually available as separate map sheets, although sea bed sediments and Quaternary geology, or sea bed sediments and solid geology may be shown on the same map sheet. The BGS 1:250 000 map sheet areas across the UKCS are shown in Figure 4, this includes those areas originally proposed, but never actually published. An example sea bed sediment and Quaternary geology map is shown as Figure 5

The 1:250 000 Quaternary geology maps plus the Holocene thickness (section 2.1.3) and bedforms (section 2.1.4) ancillary maps are of particular interest in the study of marine aggregate resources, as many Quaternary formations are proven to be aggregate-bearing. However, unlike the solid and sea bed sediment maps, UK coverage of published Quaternary geology maps is incomplete, and large data gaps exist as shown in Figure 6.

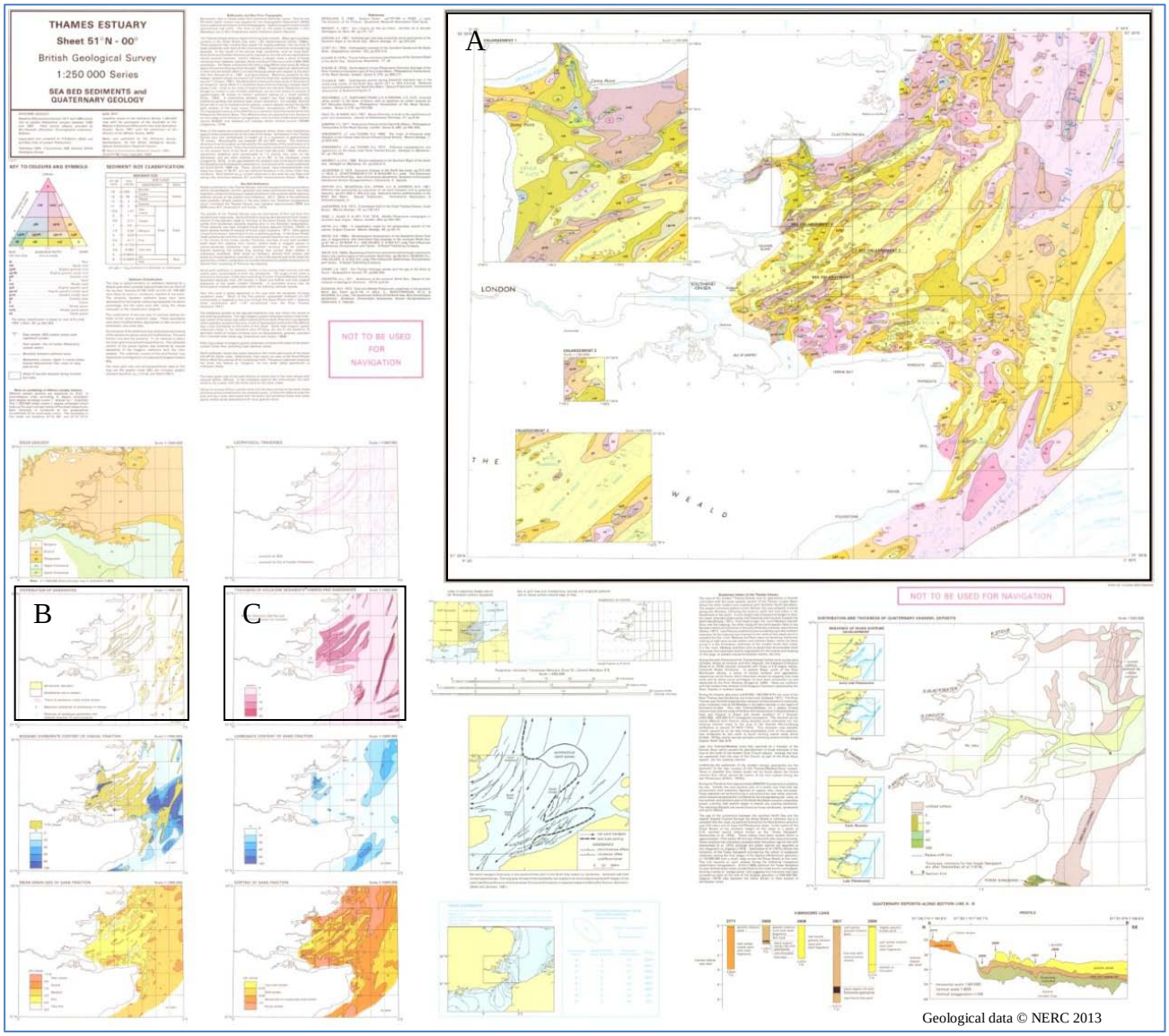

Figure 5: Example of a 1:250 000 Geological Map (UTM Series) (sea bed sediments and Quaternary geology map for the Thames Estuary). A = sea bed sediments, B = distribution of bedforms and C= thickness of Quaternary sediments.

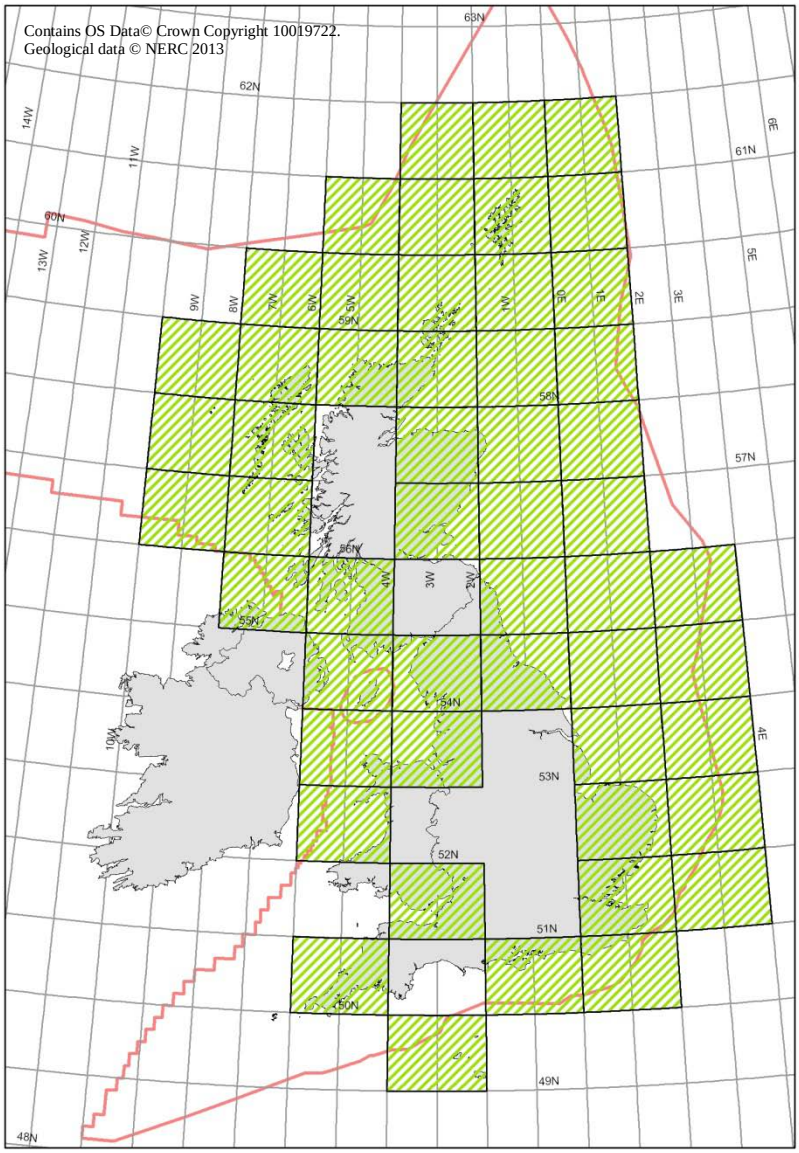

Figure 6: Coverage of Quaternary maps

2.1.3 Thickness

Some of the 1:250 000 sea bed sediment maps contain ancillary maps of the thickness of Holocene sediments underlying sandwaves. These maps are generally reproduced at 1:1 000 000 scale. These data are based on analysis of core and seismic records. It includes the thickness of all Holocene formations, i.e. deposits of less than 10 000 years old, but there is no differentiation of different lithologies or formations, which can be an issue when considering only sediments with potential as an aggregate resource. The distribution of map sheets that contain Holocene thickness ancillary maps can be seen in Figure 7 and an example of the information contained can be seen in Figure 8.

These maps are important to the aggregate resources assessment of the UKCS. Where data are available they have been used to determine the presence of sediments thick enough to constitute an aggregate resource. For the large areas where Holocene thickness maps have not been produced, information relating to the thickness of sediments has been sourced from elsewhere. Alternative sources of this information are BGS Marine Aggregate Surveys (section 2.3.1) or new interpolations generated by review of available core and shallow seismic data.

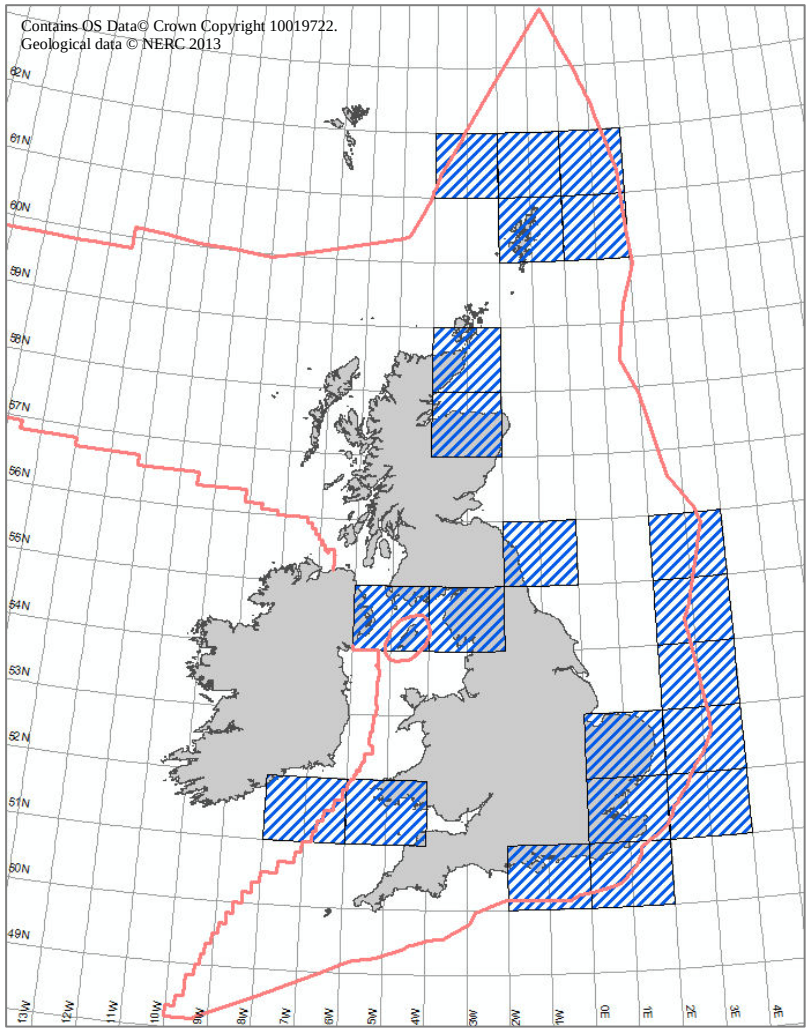

Figure 7: Coverage of Holocene thickness ancillary maps

Although these data have been used in the aggregate resources assessment of the UKCS, they do have significant limitations, in that they refer to the total thickness of all Holocene sediment, rather than sediment that may be prospective for aggregate. As a result, when modelling these data to determine prospective aggregate thickness a degree of quality control was applied. This took the form of ground truthing areas shown as thick sediment using core records to prove the presence of resources at depth.

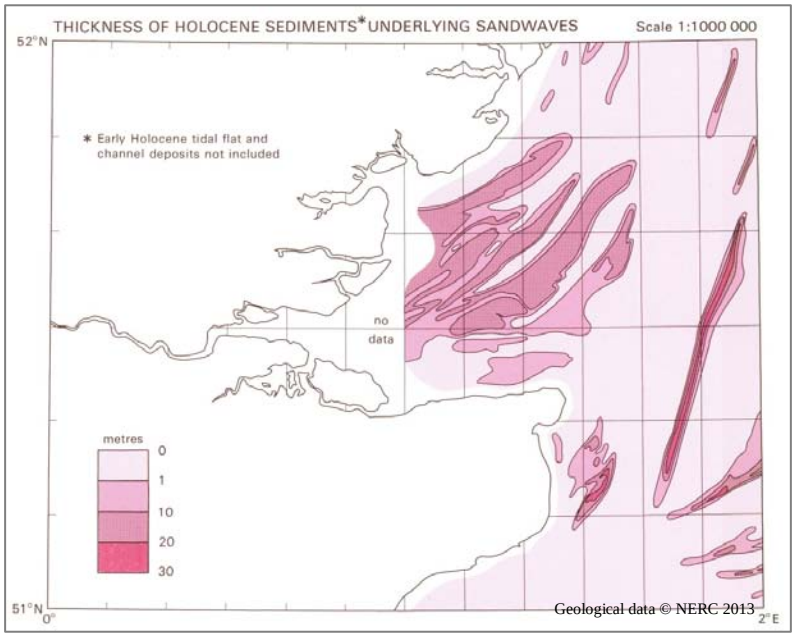

Figure 8: Example of a 1:1 000 000 Holocene thickness ancillary map (from 1:250 000 sea bed sediments and Quaternary geology map for the Thames Estuary)

2.1.4 Bedforms

Some of the 1:250 000 sea bed sediment maps also contain ancillary maps of the distribution of sand waves. These maps are generally reproduced at 1:1 000 000 scale and are primarily based on analysis of echo sounder, side scan sonar, seismic records and bathymetry. There is no single ancillary map style and useful data can be found in a range of formats, including:

- distribution of sandwaves
- generalised bedforms
- sea bed features
- sea bed depositional characteristics

The distribution of map sheets that contain the most widely available format, i.e. distribution of sandwaves, can be seen in Figure 9 and an example of the information contained can be seen in Figure 10.

Along with the sand wave distribution ancillary maps, other bedforms prospective for aggregates, such as sand and gravel banks, have been used to supplement this dataset. These data have been interpreted by digitising polygons around obvious major bedforms and similar bathymetric features identified via bathymetric and multibeam data.

Digital data for suitable bedforms have been used in the aggregate resources assessment of the UKCS shelf as proxies for sediment thickness. It was assumed that these bedforms contain material suitable for economic extraction at a thickness of one metre or greater. These data were integrated with both the Quaternary formations (where appropriate) and Holocene sediment thickness to produce a map of total sediment thickness.

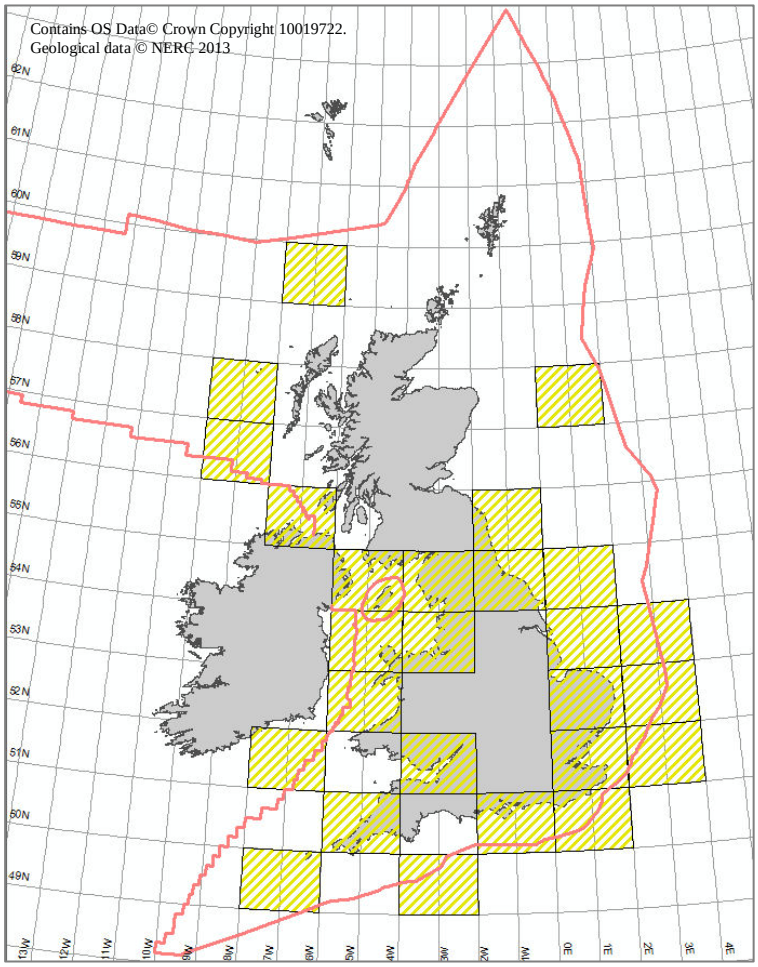

Figure 9: Coverage of sand wave distribution ancillary maps

Whilst containing the best available information for many areas of the UKCS data collated from the ancillary maps have limitations, principally of scale, when considered for use in a national aggregate study. This is especially true when compared to more recent detailed studies such as undertaken by the Regional Environmental Characterisation Surveys (section 2.3.3) and the detailed multibeam interpretation used to map bedform distribution as part of the aggregate resources assessment of the UKCS. The incomplete coverage of the data was also a issue for use in a national model.

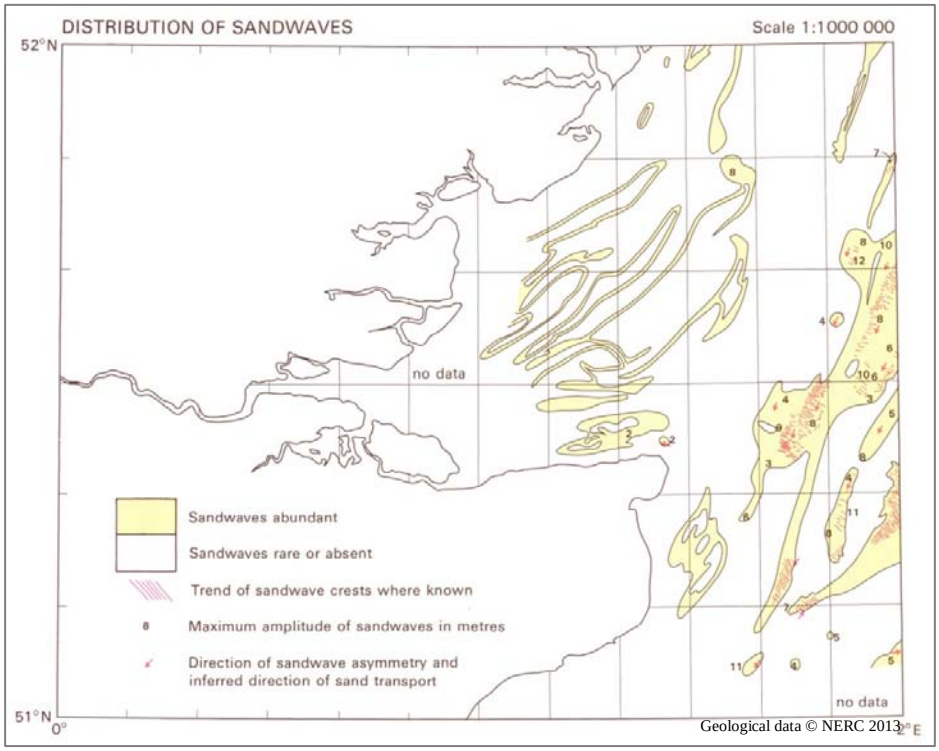

Figure 10: Example of a 1:1 000 000 sand wave distribution ancillary map (from 1:250 000 sea bed sediments and Quaternary geology map for the Thames Estuary)

2.1.5 DigSBS250

DigSBS250 (Figure 11) is the BGS digital dataset detailing the distribution of sea bed sediments. The original version of DigSBS250 was digitised from the scanned versions of the hard copy 1:250 000 scale sea bed sediment maps. The current version (Version 3) has been updated using new offshore sample and multibeam data (including back scatter where available), by directly modifying the digital version.

DigSBS250 provides mapping of the distribution of sea bed sediment types. The boundaries between sediment classifications, or types, are delineated using sample descriptions and particle size analyses, seafloor topography derived from shallow geophysical data and, where available, multibeam data (including multibeam backscatter) and side scan sonar profiles.

The sea bed sediments theme is only mapped offshore, where it commonly forms a veneer on the sea bed. The map is based mainly on sea bed grab samples of the top 0.1 metres, combined with cores and dredge samples where available. A modified Folk triangle classification (see Figure 19) has been used based on the gravel percentage and the sand to mud ratio. This dataset covers all of the UKCS and slope and extends into adjacent European waters.

The DigSBS250 dataset is available to view on the Marine Environmental Mapping Programme (MAREMAP) website:

http://www.maremap.ac.uk/index.html

Further information can also be found on the BGS internet pages:

http://www.bgs.ac.uk/products/offshore/DigSBS250.html

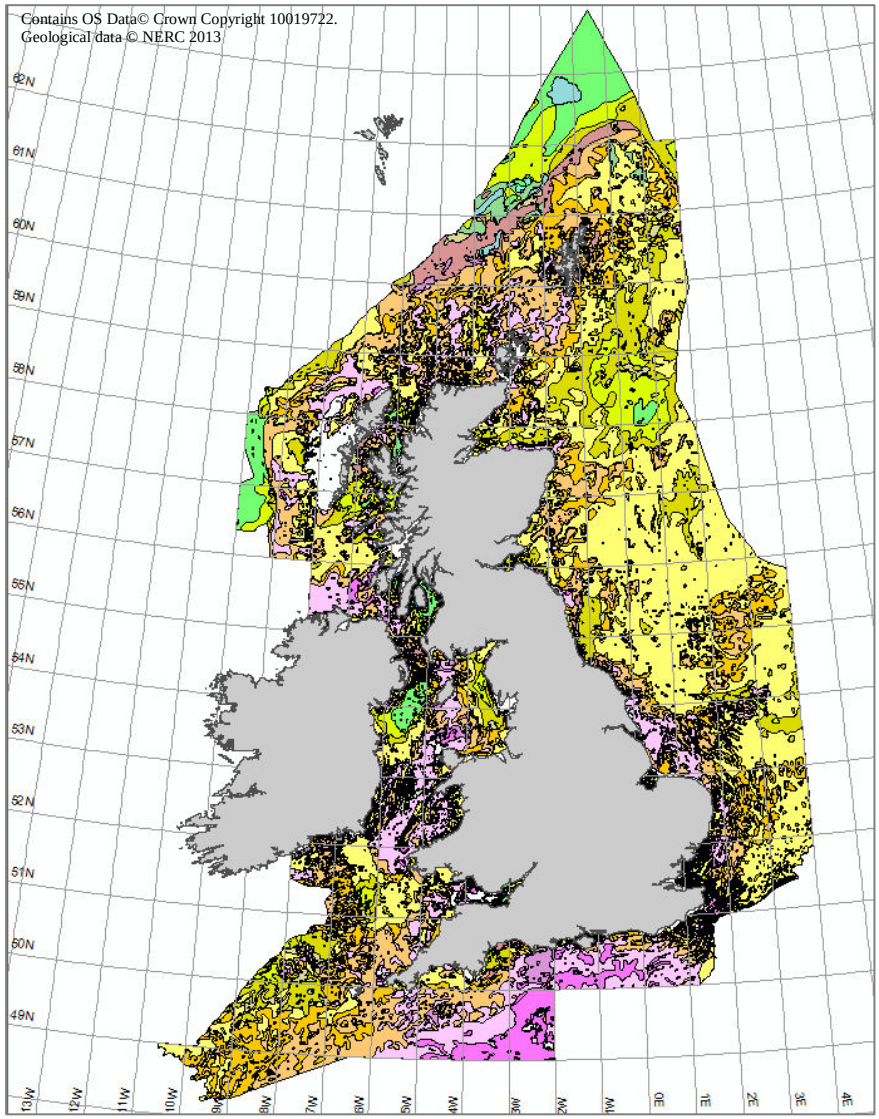

Figure 11: DigSBS250, the BGS digital dataset detailing the distribution of sea bed sediments

In the context of marine aggregate resource mapping, DigSBS250 represents a rapid way to identify the composition of the sea bed sediments to determine if they are suitable as an aggregate resource, at a scale suitable of a regional overview. DigSBS250 has been used in the aggregate resources assessment of the UKCS to identify areas that are not suitable for aggregate resources. This ensures unsuitable areas, for example areas of till, bedrock and biogenic reefs, are not included in the model.

The main limiting factor with this dataset is that in many cases the top 0.1 metres of the sea bed may not be representative of the underlying thickness of sediment (from the Holocene thickness and bedform maps) due to the actions of sea bed currents on these sediments. With this in mind, care was taken when using properties of sea bed sediments as a proxy for sediments at depth. Analysis of cores and shallow seismic was used to ground truth results.

2.1.6 Geophysical Data

BGS has access to a wide range of geophysical data including data from:

- Seismic reflection
- Seismic refraction
- Gravimetry

- Magnetic techniques

When considering marine aggregate resources, the only geophysical data of particular relevance to a regional reconnaissance survey are those that provide information on the shallow sub-surface, therefore, data collected using seismic reflection techniques. Within BGS, the most widely available data with resolution suitable for the uppermost 20 metres are in the form of boomer and pinger records. Like other BGS marine datasets, the majority of the data were collected by surveys during the late 1960s to early 1990s. New data are being added as surveys are undertaken, although recent BGS surveys are generally more focussed on acquiring multibeam data.

The spatial extent of BGS geophysical data are best viewed as the track the ship took whilst undertaking the survey, as shown in Figure 12. Fix points are also available, giving locations along each track that allow for easy spatial interpretation of the data.

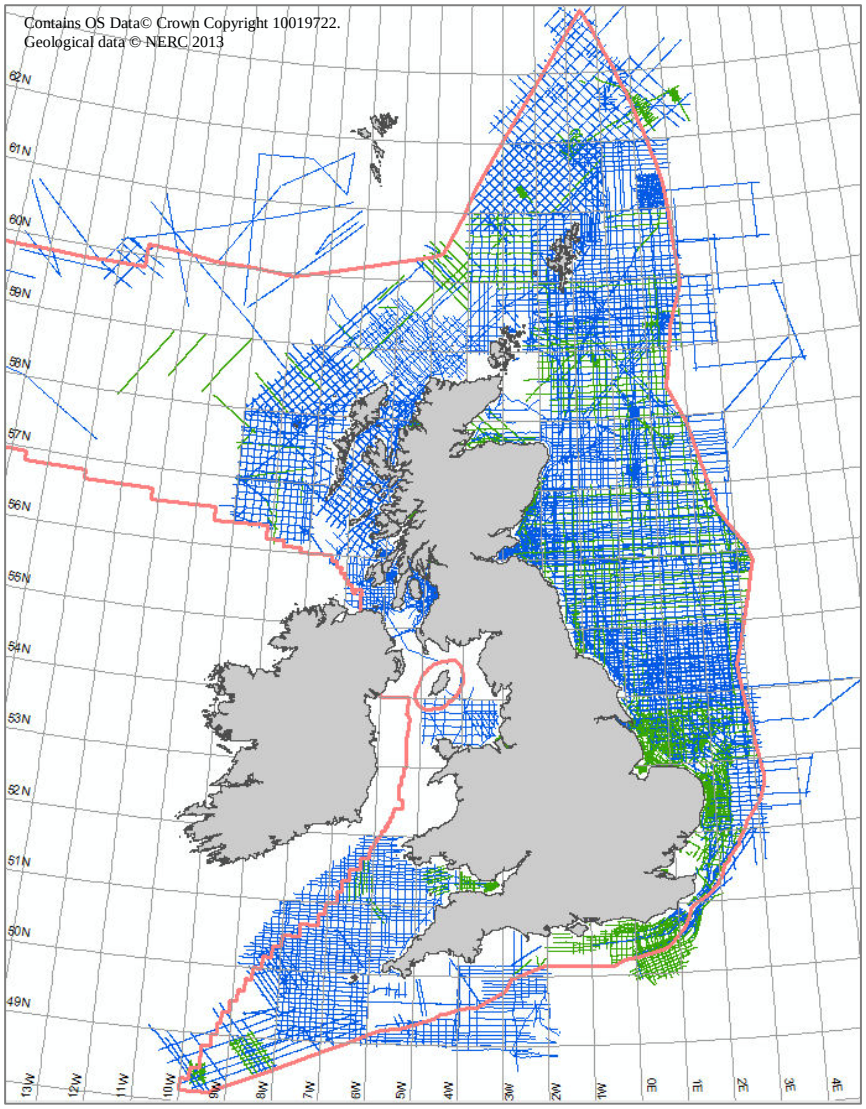

Figure 12: Boomer (blue) and pinger (green) coverage held by BGS for the UKCS

These data are supplemented by third party data from other non-commercial organisations and from commercial companies which have been deposited at BGS. These include data from the oil and gas industry, and aggregates industry, which are available for internal BGS use.

Shallow seismic data were collected as part of the REC surveys (section 2.3.3) and are available from the Centre for Environment, Fisheries and Aquaculture Science (CEFAS), who managed the REC programme. These data are also archived with, and are available from, the Marine Environmental Data and Information Network (MEDIN) Data Archive Centre (DAC) system.

Data from site investigations for some windfarm sites are available from the Collaborative Offshore Wind Research into the Environment (COWRIE) Data Management System via The Crown Estate (TCE) (section 2.3.4).

These data from modern shallow geophysical surveys are of great value in regional aggregate resource studies and have been used extensively in the aggregate resources assessment of the UKCS. Data from shallow seismic records have been used to truth areas of the model where results from other data sources seemed misleading or ambiguous. This dataset has also been used to ascertain the thickness of sediment for areas where no existing thickness data are available.

Issues involved in using these records for marine aggregate work are focused on the quality of the data, which can vary considerably. Some records, due to the equipment used, the age of the survey, the sea conditions at the time of survey, or the setup of the equipment onboard ship have resulted in poor resolution for the area of primary interest, i.e. the top 1-5m of the sea bed. This can result in some records being unusable for sub-bottom interpretation, although this can vary from line to line within a single survey.

2.1.7 Core Data

BGS hold core data collected as part of their survey work, plus some cores collected by third party organisations and deposited with the BGS for archive purposes. The most important types of core used to define aggregate properties are vibrocores and gravity cores, which are treated differently with regard to aggregate resource prospectivity studies. Other types of core exist, e.g. from drilling activities, but these hold little interest to marine aggregate resource study as the equipment is designed look at deep geological formations and recorded little information for the top 5 metres. Figure 13 shows the coverage of core held by BGS for the UKCS.

Vibrocorers use a coring technique which involves pushing a vibrating core tube into sediment and removing it with a core sample intact inside the tube up to a maximum length of 6 metres. This technique works well for stiff sediments and muds.

Gravity corers are dropped under free-fall from some height above the sea bed, and use a 0.5 ton (minimum) lead weight attached to the top of the coring tube to drive the corer into the sea bed. This technique gets excellent recovery in soft to very soft sediments, but is not very good in firm sands, or gravels.

Observation and analysis will be carried out on these types of core. In addition, a log will be generated to show detailed information at specific depth internals. Many of these will be hand produced onboard ship, with some captured digitally using log drawing software.

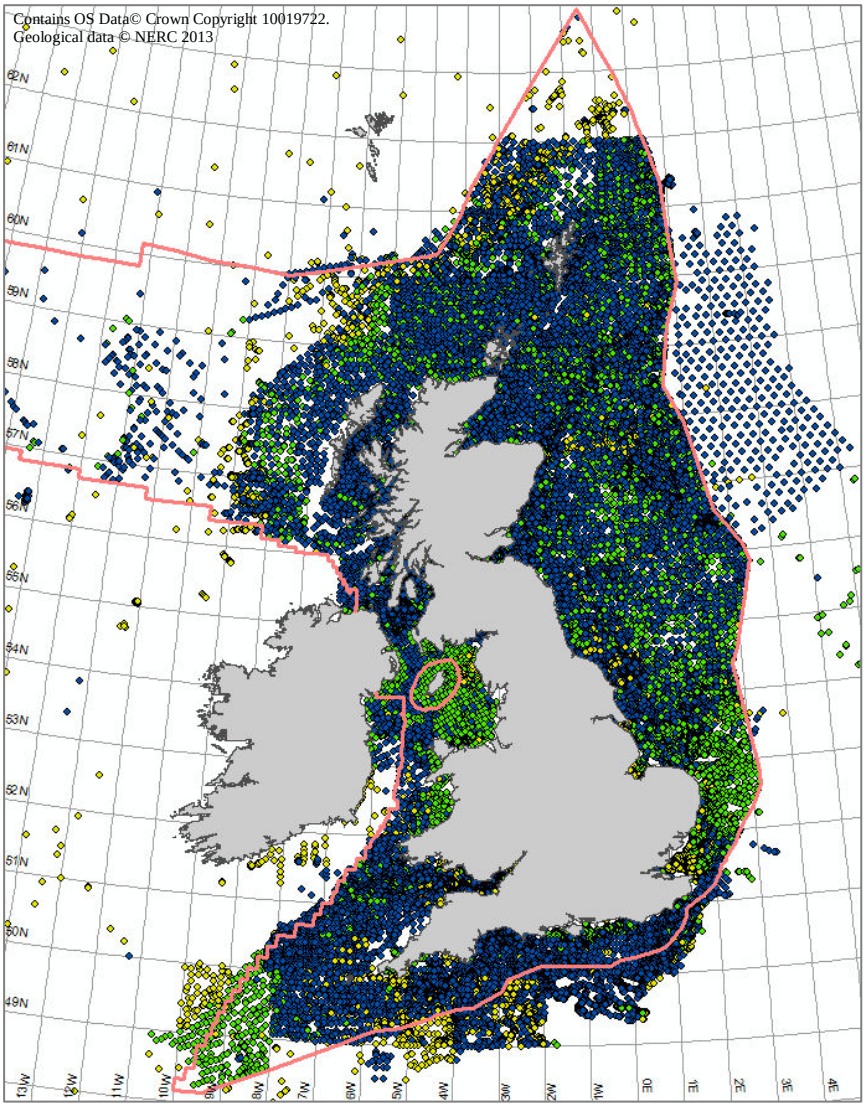

Figure 13: Vibrocore (blue), gravity core (green) and other core (yellow) coverage held by BGS for the UKCS and adjacent areas

Interpretation of a log is the quickest way to ascertain information on sub surface aggregate properties. Coverage of core data is, for the most part, good, making this dataset a useful tool for regional studies. Unfortunately, not all data from the logs are captured in a digital format, and are not available for use in specialist correlation software. Due to this limitation, core data have mainly been used in the aggregate resources assessment of the UKCS to ground truth areas of the model where results from other data sources seem misleading or ambiguous. Core data have also been used to fill in gaps in mapping of sediment thickness for selected areas.

The main limiting factors when using core data for regional aggregate resource studies is the time taken to view and correlate multiple logs, the sporadic coverage and the shallow depth of the cores. Coverage is generally good but is not uniform; data gaps are present for some key areas, e.g. east of the the Humber Estuary. Cores often have limited penetration in coarse sediments, which can resist both the vibrocorer and gravity corer techniques. As such, recovery in key areas prospective for aggregate resources, for example gravelly sediments, will often be low.

2.2 BATHYMETRIC DATASETS

Bathymetry can be used to define sea floor features and bedforms that may be prospective for aggregate resources. BGS has access to a national bathymetry dataset, DigBath250, however the

resolution of a 1:250 000 dataset is generally too low to be of use to define individual aggregate bearing features.

The Department of Environment, Food and Rural Affairs (DEFRA) have developed a high resolution Digital Elevation Model (DEM) from United Kingdom Hydrographic Office (UKHO) bathymetric data. BGS has been given access to this dataset, licensed via The Crown Estate. This high resolution bathymetry is of significant benefit in the mapping of marine aggregate resources and allows for the rapid definition of bedform features such as sand banks and areas of sand waves. An example of this dataset can be seen in Figure 14.

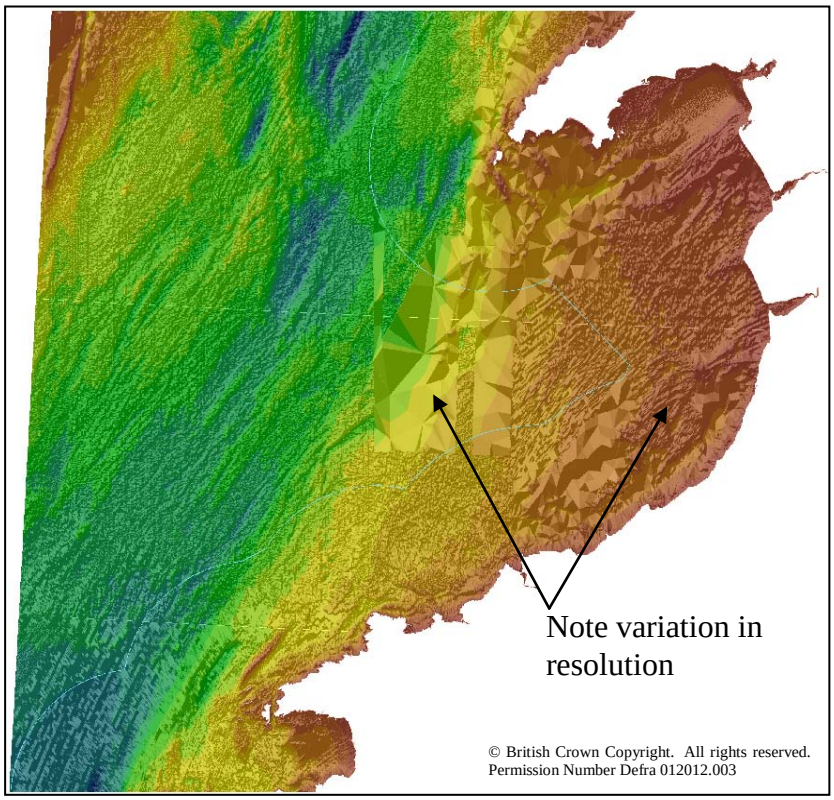

Figure 14: Example of DEFRA bathymetry (from Cardigan Bay)

2.3 COMMISSIONED AND COMMERCIAL WORK

Numerous studies focusing on marine aggregate resources have been undertaken – those conducted by BGS, but commissioned by third parties, and those carried out by external organisations. BGS has access to many of these reports, and the datasets referenced therein.

The most significant commissioned work undertaken by BGS includes:

- regional reports completed on behalf of The Crown Estate and the Department of the Environment, based on desk study analysis and more detailed reports building upon the regional assessments, where new survey work was undertaken (1986 - 1992) (section 2.3.1)
- a review of beach recharge material based on desk study analyses, commissioned by the Construction Industry Research and Information Association (CIRIA) (1996) (section 2.3.2)
- more recently BGS was heavily involved in the compilation of the REC surveys, these are regional scale surveys commissioned by the Marine Aggregate Levy Sustainability Fund (MALSF). The REC surveys have collected a wealth of new data, much of which is significant to aggregate resource studies (section 2.3.3)

BGS also has access to many sources of commercial data and reports that are relevant to aggregate processes, these include, data for windfarm sites, data from oil and gas exploration, data from renewable energy sites (e.g. the proposed Severn barrage) and data from the UKHO.

2.3.1 Marine Aggregate Surveys

Four regional reports were commissioned by The Crown Estate and the Department of the Environment from between 1986 and 1992. These covered:

- The Southern North Sea
- The South Coast
- The East Coast
- The Irish Sea

These desk studies aimed to indicate the approximate location of marine aggregates on a regional scale using data collected mainly by BGS marine survey work. They contain brief descriptions of the resources within the study area along with maps detailing surface distribution of coarse and fine aggregate (using 5 mm as the cut off for coarse aggregate, this is based on now outdated British Standards), bathymetry, sediment thickness, sample points and dredging areas.

Complimenting the original Marine Aggregate Survey regional report series three more detailed reports were also commissioned, an example of some of the data contained within these is shown in Figure 15:

- Great Yarmouth and Southwold
- Isle of Wight and Beachy Head
- Humber

These reports focused in on areas of particular interest indicated by the regional publications and involved new survey work, collecting new samples and seismic data to prove aggregate resource deposits.

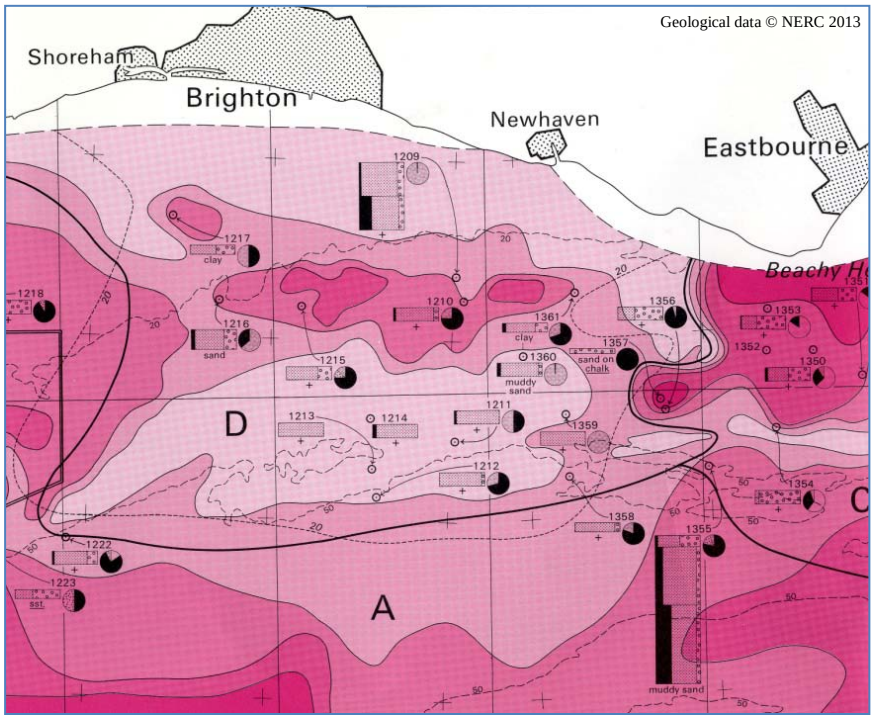

Figure 15: Example of the data contained within Marine Aggregate Survey report series, in this case, the distribution of coarse sediments and core logs

These reports contain information useful for a regional overview of marine aggregate resources. However, a major limiting factor in the use of data contained within these reports is that all particle size analyses has been conducted using 5 mm as the boundary between sand and gravel (as opposed to the 2 mm of the Wentworth scale, or the 4 mm of the current European Standard). Therefore, these data are not easily integrated with modern data that conform to current standards.

2.3.2 Other BGS Reports

The most recently published BGS report focused on assessing the aggregate resource potential of an area of the eastern Irish Sea between North Wales and southern Scotland. This was also commissioned by The Crown Estate (Morgan *et al.*, 2012).

This report used existing data, principally from the DigSBS250 dataset to assess broad areas for aggregate resource potential. It acknowledges both the lack of data in many areas for use in regional studies and also the unreliability, in many cases, of using sea bed sediment data as an indicator for aggregate resources.

The Construction Industry Research and Information Association (CIRIA) have also commissioned BGS to undertake work on marine aggregates. These include a study into beach recharge material (Humphreys, 1996) and a study into marine aggregate resources in north-west Europe (Humphreys *et al.*, 1999).

BGS has also produced several regional reports regarding the geology of the UKCS and overview reports detailing sea bed characteristics and properties that contain information of relevance to marine aggregates such as Morgan *et al.*, 2012.

2.3.3 Regional Environmental Characterisation (REC) Reports

In 2002 the Government imposed a levy on all primary aggregate production (including marine aggregates) to reflect the environmental cost of winning these materials. A proportion of the revenue generated was used to provide a source of funding for research aimed at minimising the effects of aggregate production. This fund, delivered through DEFRA, is known as the Aggregate Levy Sustainability Fund (ALSF), a spate fund was created specifically for marine related aggregates – the Marine Aggregate Levy Sustainability Fund (MALSF). The aim of the Marine Aggregate Levy Sustainability Fund (MALSF) programme was to promote environmentally friendly aggregate extraction in the marine environment in English waters.

Between 2008 and 2011 the MALSF commissioned a series of REC projects to develop understanding of Britain's submerged habitats and heritage. These projects collected new, high quality, geological and biological survey data to enable broad scale characterisation of sea bed habitats, biological communities and historic environmental assets.

Four REC projects were undertaken during Round 3 of the MALSF (2008-2011):

1. East Coast
2. Humber
3. South Coast
4. Outer Thames Estuary

(Figure 16 shows the location of these study areas.)

The Round 3 projects were preceded by an additional two, similar, REC-type regional projects undertaken during 2004 - 2005:

- Eastern English Channel Marine Habitat Mapping (EECMHM) funded by the MALSF (Round 2)
- Outer Bristol Channel (OBC) funded in part by the MALSF (Round 1)

Survey data acquired during the REC projects include geophysical surveys (sub-bottom profiler (boomer), side-scan sonar, magnetometer, bathymetry and gridded bathymetric datasets) and environmental surveys (imagery (video and still), species lists, particle size analysis and vibrocores).

All survey and interpreted data have been made available through an online GIS and database allowing for easy access and viewing of data:

http://www.marinealsf.org.uk/

Please note that the MALSF website will be closed in 2014, after a three year extension beyond the life of the MALSF programme, which ended in early 2011.

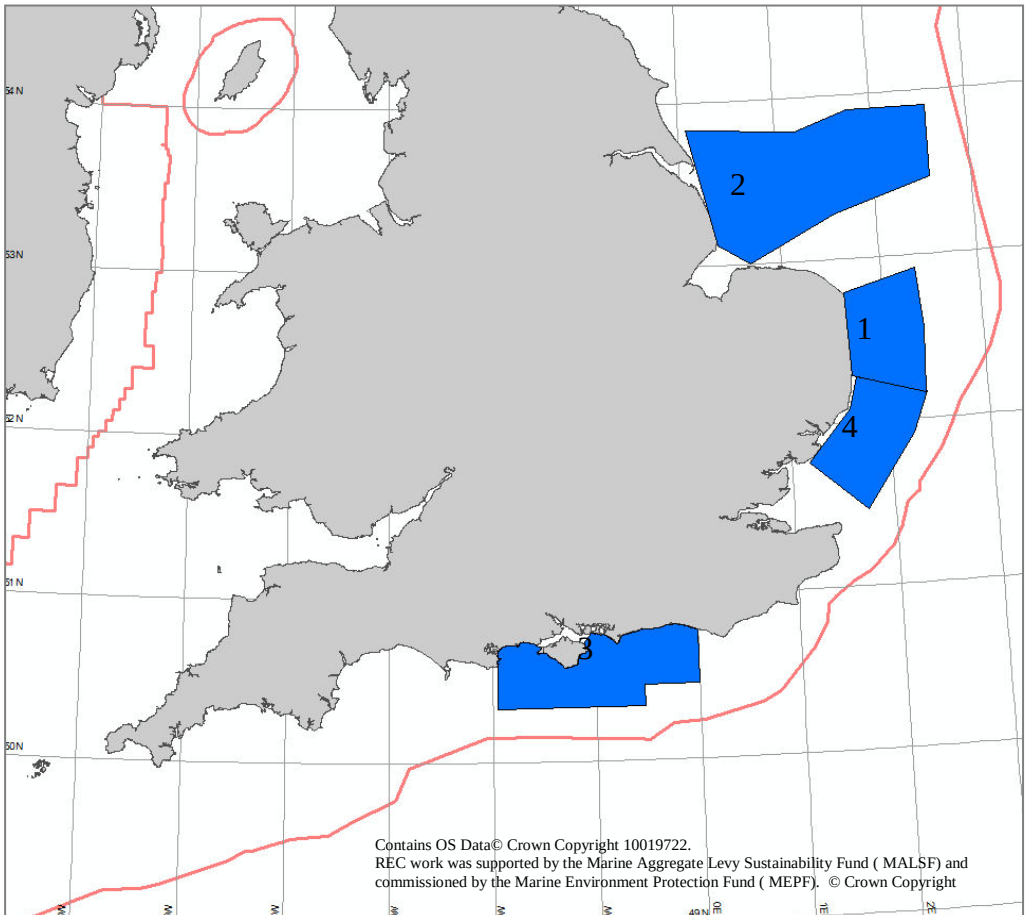

Figure 16: The four MALSF funded REC study areas

All of the MALSF survey data have been archived in the MEDIN DAC network for long-term storage and delivery.

Further information can be found on the MEDIN internet pages:

http://www.oceannet.org/

Although REC data were not collected with marine aggregate resources in mind, much of the data collected are very relevant to aggregates, especially in the case of geophysical surveys. Also, for new samples particle size analysis was undertaken with a full range of sieve sizes, allowing calculation of the gravel fraction to conform to European Standards.

Interpreted data from these surveys also have applications in aggregate resource mapping, with regard to bedform (Figure 17) and Quaternary mapping. However, not all surveys contain sub-bottom analysis of sediments.

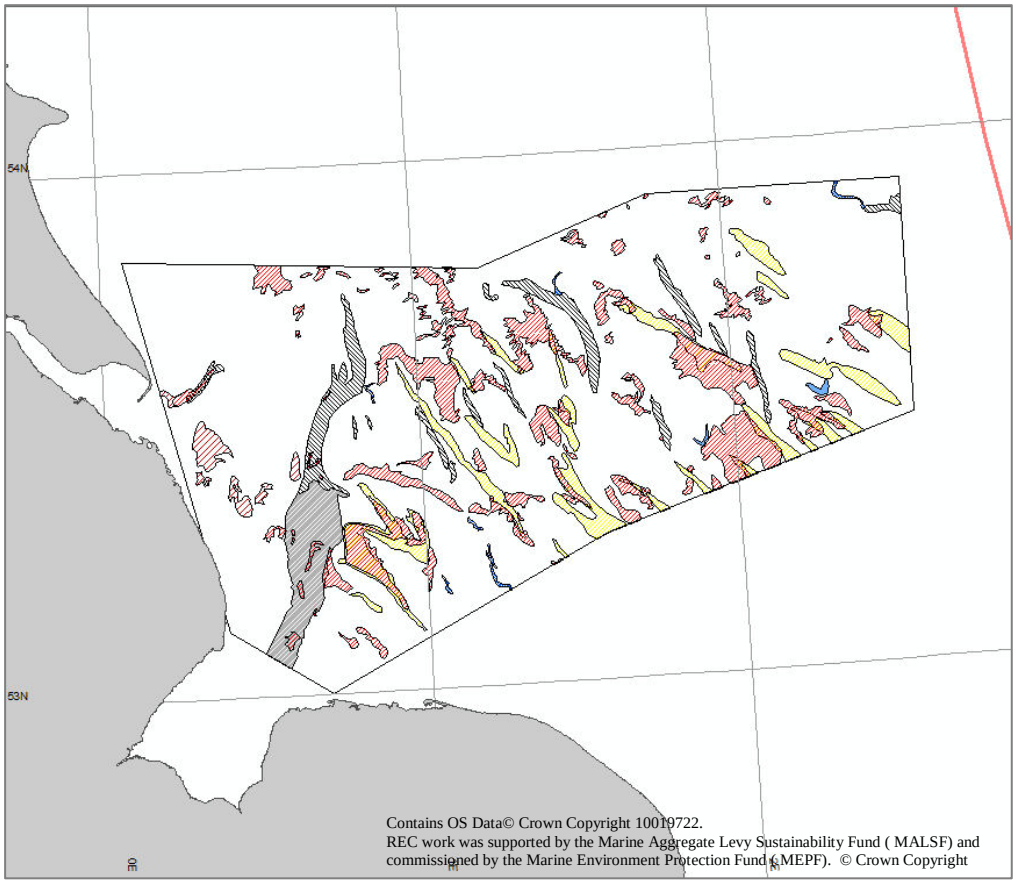

Figure 17: Example of interpreted data from a REC survey (bedform mapping in the Humber REC area)

2.3.4 Renewable Energy

Data from many recent investigations into the sea bed from the renewable energy industry are in the public domain. Site investigations for wind farm sites have collected high quality data, although for small areas consisting of detailed bathymetry, sediment samples and geophysical data and borehole logs.

Data generated by windfarm investigation as part of The Crown Estate's second licensing round are stored in an online database, Collaborative Offshore Wind Research into the Environment (COWRIE), and through this all data submitted to The Crown Estate should be available to download:

http://data.offshorewind.co.uk/

These data are fragmented, and are generally focused on specific areas and therefore of limited value for use in regional studies. However, they do have use in resolving issues or ground truthing geological interpretations for areas where other data may not be available.

Other data from renewable energy studies are also available. For example a considerable amount of data are available for the Bristol Channel as a result of work conducted relating to the proposed Severn Estuary tidal barrage.

2.3.5 IMAGIN Study

IMAGIN (The Irish Sea Marine Aggregates Initiative) was a study focused on mapping aggregate resources in the southern Irish Sea, extending from the coast of Ireland to Wales and the north of England. This study had the purpose of developing a strategic framework and scientific rational to underpin further development for Irish Sea aggregates and develop operational guidelines and regulatory processes.

The project was completed in 2008 and the results can be viewed in an online GIS:

http://imagin.ucc.ie/atlas.php

Although this work primarily focuses on Irish Waters the broad areas of aggregate resources outlined give an indication to the general presence of marine sand and gravel.

2.3.6 United Kingdom Hydrographic Office

The UKHO have generated a wide range of data relating to the marine environment over a long period of time, often, in a mix of formats which include legacy paper records. The UKHO also manage the Marine and Coastguard Agency (MCA) generated sea bed survey data.

BGS holds significant amounts of UKHO and MCA data, primarily for BGS own use. These include sea bed texture maps, which are charts created during UKHO surveys which relate to sea bed features. These charts are at a large scale and were considered too detailed for use in this regional study.

Much information regarding sea bed properties is available from the Admiralty Charts produced by the UKHO. These are paper maps and contain detailed bathymetric data and textual descriptions on sea bed properties. As they are non-digital and descriptions of sea bed samples are often qualitative rather than quantitative their use in regional aggregate surveys is limited. However they do contain information regarding the location of sand banks and sand wave fields which, in some cases, has been digitally captured for the marine aggregates map.

2.4 DATA SOURCES FOR NON-AGGREGATE MINERALS

Data sources for non-aggregate minerals (coal, evaporites and metallic minerals) are limited when compared to those of aggregate resources. Coal and evaporite minerals occur at depth so the limited number of deep offshore borehole records BGS has access to can be used to prove these deposits. Of significant use is data gathered from peer reviewed literature and BGS reports. BGS has compiled reports mapping offshore deep coal basins (at a small scale) as well as stratigraphic reports outlining the presence of evaporite-bearing sedimentary basins.

Information on metallic mineral occurrences is sparse; there is limited geochemical information offshore, mainly concentrated around Scottish waters (Figure 18). Of more use is recorded trials and exploration for metallic mineral extraction. More information on these minerals can be found in Section 3.7.

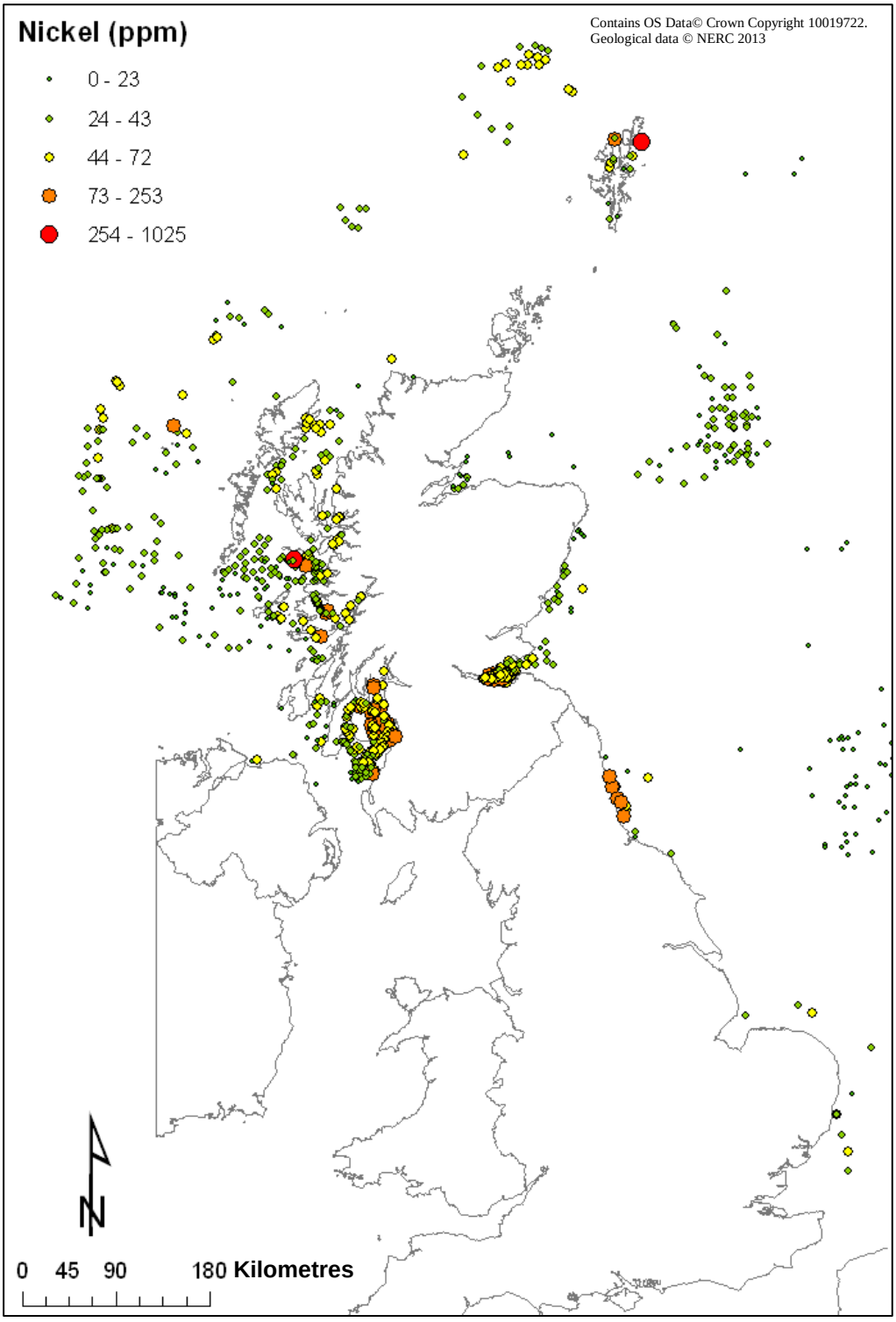

Figure 18: An example of coverage for geochemistry data (showing nickel concentrations) for the UKCS

3 Development of a national marine aggregate resource model

3.1 INTRODUCTION

The marine aggregate resource maps have been produced by the collation and interpretation of a wide range of information, much of which is spatially variable and not always available in a consistent and convenient form. As a result of this all data sources were integrated into a GIS to provide the best possible information on a national scale. By combing numerous sources of information within a GIS environment it was possible to apply criteria relating to the properties required for sand and gravel resources as defined by consultation with industry and relevant European Standards for aggregates and so define areas of aggregate resources.

This section outlines the main input datasets or themes that were utilised to create the national model, and the development of the data to achieve a fit-for-purpose model, including the processing methodology and final attribution.

The following themes have been used directly in the production of the marine aggregate resource map:

- Sea bed sediment from DigSBS250
- Sediment thickness
- Mud content (<0.0625mm) as a percentage of the whole sample
- D50 of the sand fraction (0.0625mm – 2.00mm)
- Gravel content (>4.00mm) as a percentage of the whole sample. This is based on statistical methods to interpolate the quantity of material in grain size fractions not held by BGS and this is explained in more detail in section 3.8.

The sea bed sediment theme is based on the BGS digital dataset DigSBS250. The superficial sediment thickness theme is primarily based on the BGS 1:250 000 Geological Maps (UTM Series) and 1:1 000 000 ancillary maps where available, supplemented by interpretation of additional cores, seismic and multibeam data. All other themes are based on analysis of physical samples collected throughout the BGS Marine Mapping Programme and open access data supplied by third party organisations. A more detailed explanation of the data provenance can be found in section 0.

The following themes have been included in the marine aggregate resource map as additional attributes deemed useful for more detailed interpretation of the identified resource blocks:

- Sand content (0.0625mm – 2.00mm) as a percentage of the whole sample
- Carbonate content as a percentage of the sand fraction (0.0625mm – 2.00mm)
- Lithic content of the gravel fraction (>2.00mm) as a percentage of the whole sample
- Carbonate content as a percentage of the gravel fraction (>2.00mm)

These additional themes are based on analysis of physical samples collected throughout the BGS Marine Mapping Programme and open access data supplied by third party organisations.

3.2 MODELLED DATA THEMES

3.2.1 DigSBS250

The sea bed sediment theme (SBS theme) is based on the BGS digital product DigSBS250 which is described in section 2.1.5. A modified Folk triangle classification (Folk, 1954) is used by BGS

for DigSBS250 based on the gravel percentage and the sand to mud ratio, as shown in Figure 19. In addition, there are areas where sea bed sediments are absent or undifferentiated, these classifications are shown in Table 1.

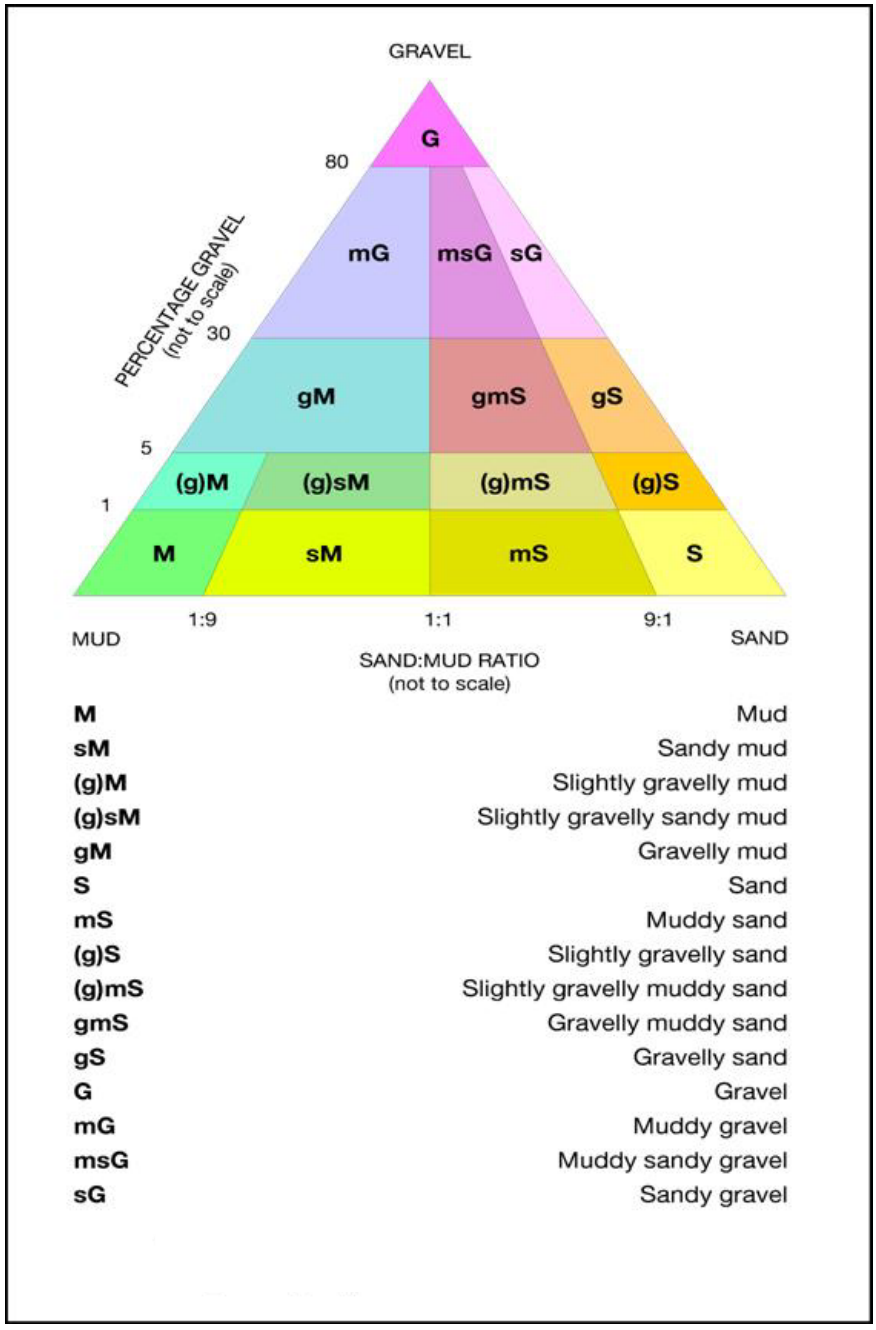

Figure 19: DigSBS250 modified Folk Classification scheme

Additional classifications used by DigSBS250	Comment
Clay and sand	Pre-Holocene deposit
Diamicton	Pre-Holocene deposit
Gravel, sand and silt	Undifferentiated
Undifferentiated solid rock	Undifferentiated
Rock and sediment	Undifferentiated
Rock and diamicton	Pre-Holocene
Mussel deposit	Biological

Table 1: Additional classifications used by DigSBS250

The combined sea bed sediment classification has been used to distinguish areas of no resource and potential resource bearing regions. Areas of no resource are the areas where sea bed sediments are absent or do not contain suitable clastic sediments (Table 1). All other classifications (Figure 19) are identified as areas of potential resource as shown by Figure 20.

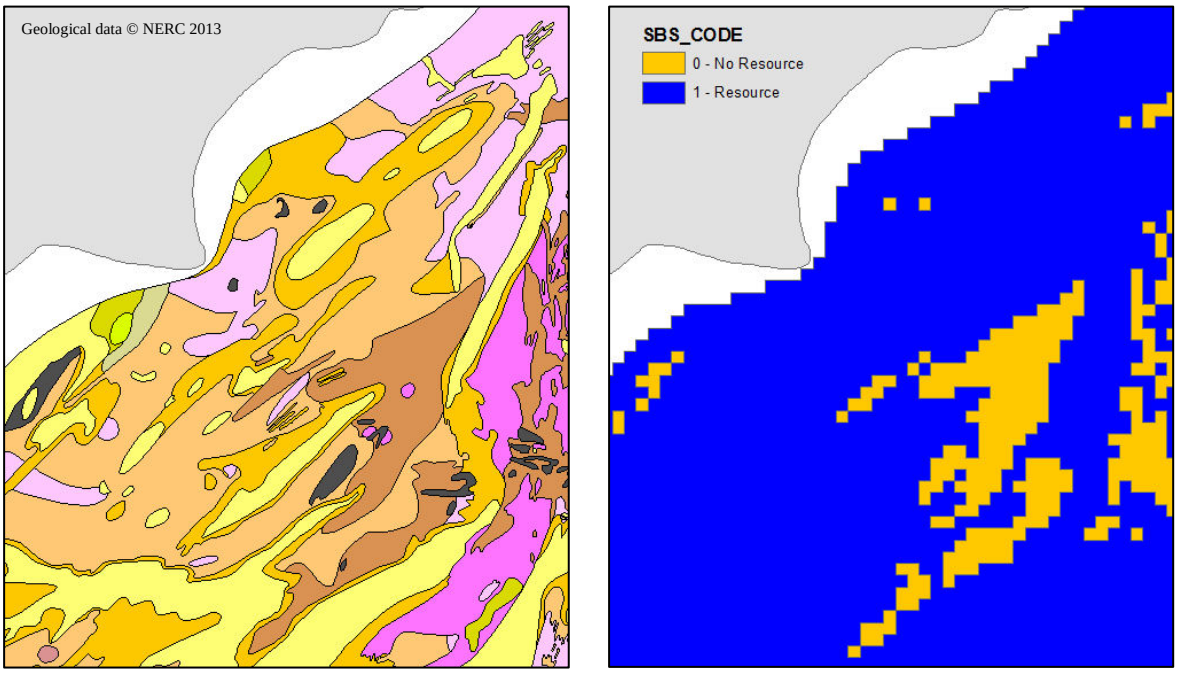

Figure 20: DigSBS250 (left) and then reclassified into areas of no resource and resource (right)

3.2.2 Sediment Thickness

The sediment thickness theme (THICK theme) is based predominantly on the current BGS 1:1 000 000 ancillary maps showing the thickness of Holocene sediments. These data have been enhanced with the use of any ancillary maps representing the distribution of various bedforms, and where necessary additional geological interpretation.

The thickness of Holocene sediments, merged with additional data on the distribution of bedforms, has been used as a base layer for the sediment thickness theme. The various bedforms have been assigned a generalised sediment thickness based on the classification in Table 2. See section 2.1.3 for more detail on the data provenance.

Bedform	Thickness classification used for bedforms
Substrate Outcrop	No Resource
Gravel Waves	Moderate
Sand Ribbons	Moderate
Sand Patches	Moderate
Sand Carpet	Moderate
Mega Ripple	Thick
Sand Wave	Thick
Sarn	Very Thick
Sand Bank	Very Thick

Table 2: Generalised sediment thickness classification used for bedforms

This base layer has been supplemented with geological interpretation of borehole and seismic data, and to a lesser extent interpretation from multibeam data. Location information was used to make a point data layer of the interpreted sediment thickness from boreholes and seismic records. The point data was interpolated using the Inverse Distance Weighted (IDW) technique (see Section 3.3.1 for more detail) to produce a grid, with a 1 km cell size. The grid was then reclassified into appropriate categories and converted to a polygon shape file. The interpretation from multibeam and bathymetric data have been captured by digitising polygons around obvious major bedforms and similar bathymetric features. The base layer and the additional interpreted data were then merged to create one seamless dataset representing total sediment thickness. Figure 21 visualises the development of this theme.

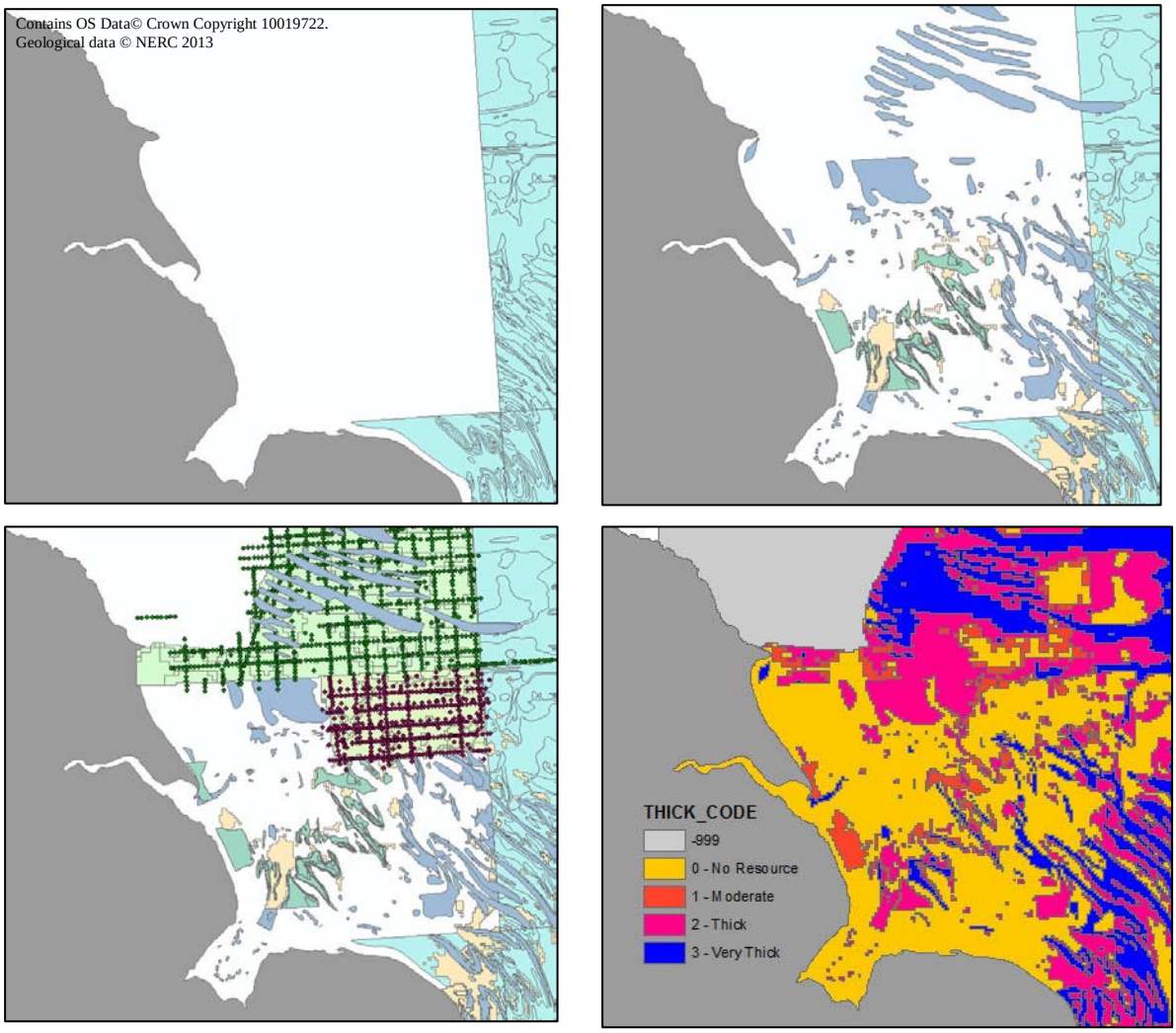

Figure 21: Thickness of Holocene sediments (top left), distribution of bedforms (top right), additional data from interpretation of shallow seismic (bottom left), and the final combined and reclassified data that represents total sediment thickness (bottom right)

Unfortunately, due to the nature of the data, there can be abrupt changes in thickness at boundaries. This is due either to the different data sources, or inconsistencies between the resolution of isopachs and the classification system used to measure superficial thickness depth across different map sheet areas.

3.2.3 Sediment Analysis

All other input themes (mud content, D50 of the sand fraction and lithic content of the gravel fraction (>4.00mm)) are the result of analysis carried out on physical samples obtained during the BGS Marine Mapping Programme, or open access data supplied directly to BGS by third party organisations. Due to the different sources, there are some slight variations within the datasets.

BGS uses the Wentworth scale for classification of sediment size (Wentworth, 1922). The Wentworth Scale is the grade scale most commonly used for sediment analysis, it uses a logarithmic scale in that each grade limit is twice as large as the next smaller grade limit. The most common analysis performed on BGS physical samples would be to attain the gravel, sand and mud percentage of a sample. This was usually obtained by wet sieving of the sample into the gravel, sand and mud fractions. BGS may also dry sieve the sand fraction (0.0625mm – 2.00mm) using either 0.5 phi or 1 phi intervals to derive other particle size parameters, such as the median grain size (D50), or sorting. BGS may hold the sieve analysis of other fractions, but only in limited areas of interest. Finally the carbonate content of each fraction may be acquired. The

carbonate content of the gravel fraction would be obtained by manual separation of the biogenic carbonate from the lithic gravel. The carbonate content of the sand fraction would usually be obtained by acid digestion of a sub sample.

Data supplied by third party organisations may not use the same divisions for sediment analysis as utilised by BGS. For example, some data may conform to the current European Standard that uses 4 mm as the boundary between sand and gravel, as opposed to the Wentworth scale that uses 2 mm. Also, MALSF samples acquired as part of the REC projects were sieved using a wider range of sieve mesh sizes, and at different intervals, than those utilised by BGS.

The mud content theme (MUD theme) is based on the percentage weight of mud in each sample (based on the Wentworth scale). This is derived from the weight of the mud-sized material that passed through a 4.0 phi (0.0625mm) sieve converted to a percentage of the total weight of sample analysed.

The D50 of the sand fraction theme (D50SAND theme) is based on sieving of the sand fraction (based on the Wentworth scale) at either 0.5 phi or 1 phi intervals. Data supplied by third party organisations have been translated to their equivalent phi interval, where possible, to maintain a level of consistency. The D50, or median particle diameter by mass, can then be derived from the resultant data.

The lithic content of the gravel fraction (>4.00mm) theme (GRAV theme) is based on the percentage weight of the gravel fraction that is not biogenic carbonate, based on hand-picking. This is derived from the weight of the gravel-sized material that passed through a -1.0 phi (2.00mm) sieve converted to a percentage of the total weight of sample analysed. Statistical methods have then been used to convert from the gravel fraction based on the Wentworth scale (>2mm) to gravel as defined by European Standards (>4mm). This is further explained in Section 3.8.

3.2.4 Additional Attribution

The following datasets have no impact on the categories used for the marine aggregate resource map, but the attributes were deemed useful for more detailed interpretation of the identified resource blocks.

The additional themes recognised as useful for more detailed interpretation of the identified resource blocks (sand content, carbonate content as a percentage of the sand fraction, lithic content of the gravel fraction (>2.00mm) and carbonate content as a percentage of the gravel fraction) are also the result of analysis carried out on physical samples obtained during the BGS Marine Mapping Programme, or open access data supplied directly to BGS by third party organisations.

The sand content theme (SAND theme) is based on the percentage weight of sand in the sample (based on the Wentworth scale). The weight of sand-sized material retained by a 4.0 phi (0.0625mm) sieve converted to a percentage of the total weight of sample analysed.

The carbonate content as a percentage of the sand fraction theme (CSAND theme) is based on the percentage weight of the sand fraction (based on the Wentworth scale) that is carbonate. This is derived by either treating the sample with dilute hydrochloric acid and reweighing after effervescence has ceased, or the Karbonat-Bombe technique (Muller and Gastner, 1971).

The lithic content of the gravel fraction (>2.00mm) theme (LGRAV theme) is based on the percentage weight of the gravel fraction (based on the Wentworth scale) that is not biogenic carbonate, usually the result of hand-picking.

The carbonate content as a percentage of the gravel fraction theme (CGRAV theme) is based on the percentage weight of the gravel fraction (based on the Wentworth scale) that is biogenic carbonate, usually the result of hand-picking.

3.3 MODELLING METHODOLOGY

3.3.1 Data Interpolation and Integration

SBS theme: DigSBS250 was reclassified into the categories below and converted to a grid, with a 1 km cell size. The resultant grid was then converted back to a polygon file for the final process that combined all the input themes.

The SBS theme has been classified into the following categories:

SBS_CODE	SBS	DigSBS250*
-999	No Data	
0	No Resource	Clay & Sand Diamicton Undiff Solid Rock Rock & Diamicton Rock & Sediment Mussel Deposits
1	Resource	Gravel, Sand & Silt All Folk Classes

*Note: This field does not form part of the final national model attribution.

THICK theme: The theme representing total sediment thickness was reclassified into the categories below and converted to a grid, with a 1 km cell size. The resultant grid was then converted back to a polygon shape file for the final process that combined all the input themes.

The THICK theme has been classified into the following categories:

THICK_CODE	THICK	THICK2
-999	-999	No Data
0	0 – 0.999m	No Resource
1	1 – 1.999m	Moderate
2	2 – 9.999m	Thick
3	>10m	Very Thick

During the BGS Marine Mapping Programme, samples were typically collected on a 4-6 kilometre spacing regime. Areas of particular scientific interest will have a denser sampling coverage, and areas where sampling is potentially difficult or not of scientific interest will have a less dense coverage. Unfortunately, there are also data gaps for certain areas, i.e. the western area of the UKCS towards Rockall and beyond. With this mixed data coverage in mind, for a national interpolation, the use of a 5 km cell size is as high a resolution as could realistically be achieved. This resolution does not eliminate the bull's eye effect caused by sparse data coverage, but does minimise the effect in areas of dense and moderately dense coverage.

For interpolation we have used the Inverse Distance Weighted (IDW) technique (Figure 22 to Figure 28), which assumes the weight of a value decreases as the distance increases from the interpolated location. Deterministic interpolation techniques apply an established mathematical formulae to the sample points. In the case of IDW, the formula is: multiply the values of the sample points that fall within a specified neighbourhood from the processing cell by a weight that is derived from the distance the sample point is from the processing location.

IDW is a local, deterministic method of interpolation. Global methods of interpolation use all available data to make predictions for the whole area of interest, but local interpolators use a

small area around a sample point to make its predictions. IDW techniques combine the notion of proximity whilst introducing gradual change based on the trend surface. The technique's biggest weakness is that it has no assessment of prediction errors and it can produce bull's eyes around sample locations, especially if the data are sparsely located.

The IDW technique is a quick interpolation method, requiring few decisions to be made regarding modelling parameters. This means that quick judgements about the data can be made to see if it exerts any spatial trend. Confidence in the output interpolated map is weakest where there are outliers or no data. It should therefore be used with caution in these areas.

The interpolation was calculated using ESRI ArcGIS Spatial Analyst Interpolation IDW tool. The relevant point data was extracted from the BGS RDBMS and interpolated to produce a grid with a 5 km cell size. The grid was then reclassified into the individual theme categories below and converted to a polygon file for the final process that combined all the input themes.

The MUD theme has been classified into the following categories:

MUD_CODE	MUD	MUD2
-999	-999	No Data
0	10 – 100%	No Resource
1	5 – 9.999%	High
2	0 – 4.999%	Low

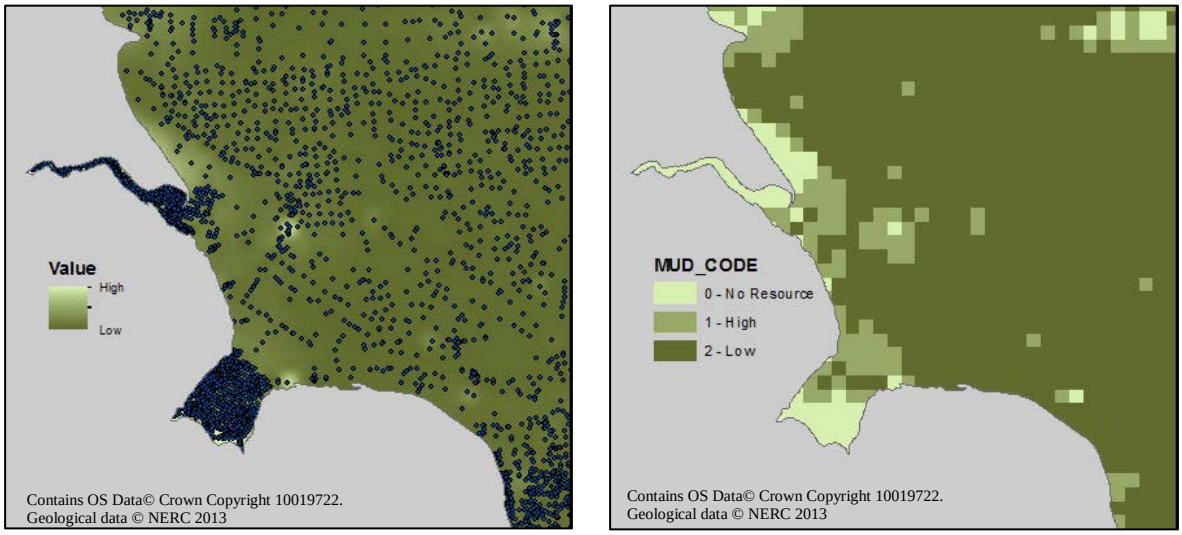

Figure 22: Original interpolation using the IDW technique for the MUD theme (left) and then reclassified to an appropriate scale (right)

The D50SAND theme has been classified into the following categories:

D50_CODE	D50SAND	D50SAND2
-999	-999	No Data
1	4phi (0.063mm) – 2phi (0.25mm)	Fine and Very Fine Sand
2	2phi (0.25mm) – 1.5phi (0.35mm)	Medium Fine Sand
3	1.5phi (0.35mm) – 1phi (0.5mm)	Medium Coarse Sand
4	1phi (0.5mm) – 0phi (1.0mm)	Coarse Sand
5	0phi (1.0mm) – - 1phi (2.00mm)	Very Coarse Sand

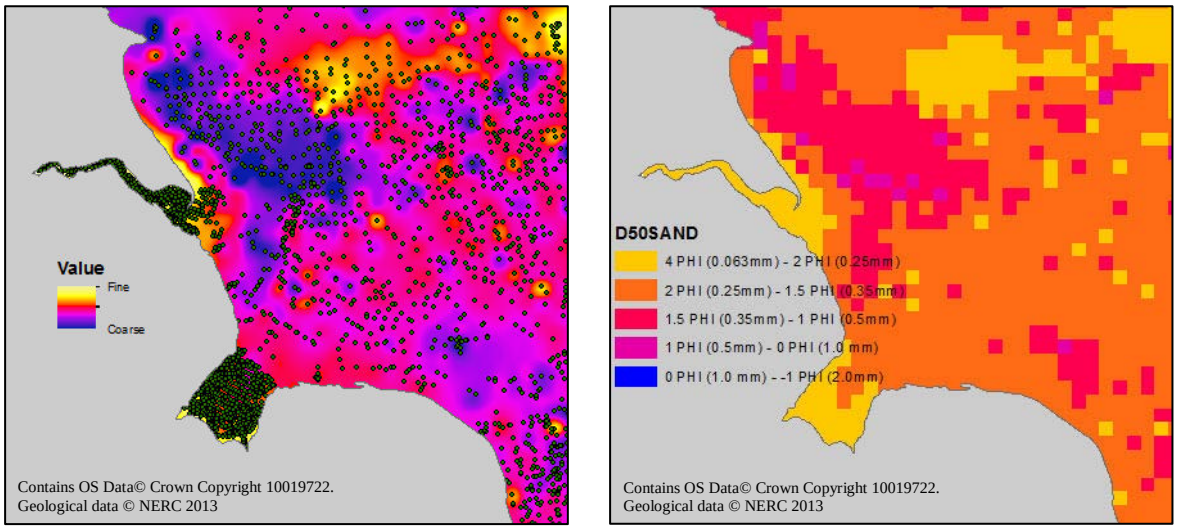

Figure 23: Original interpolation using the IDW technique for the D50SAND theme (left) and then reclassified to an appropriate scale (right)

The GRAV (gravel) theme has been classified into the following categories:

GRAV_CODE	GRAV	GRAV2
-999	-999	No Data
1	Gravel (4mm) <10%	Fine
2	Gravel (4mm) >10%	Coarse

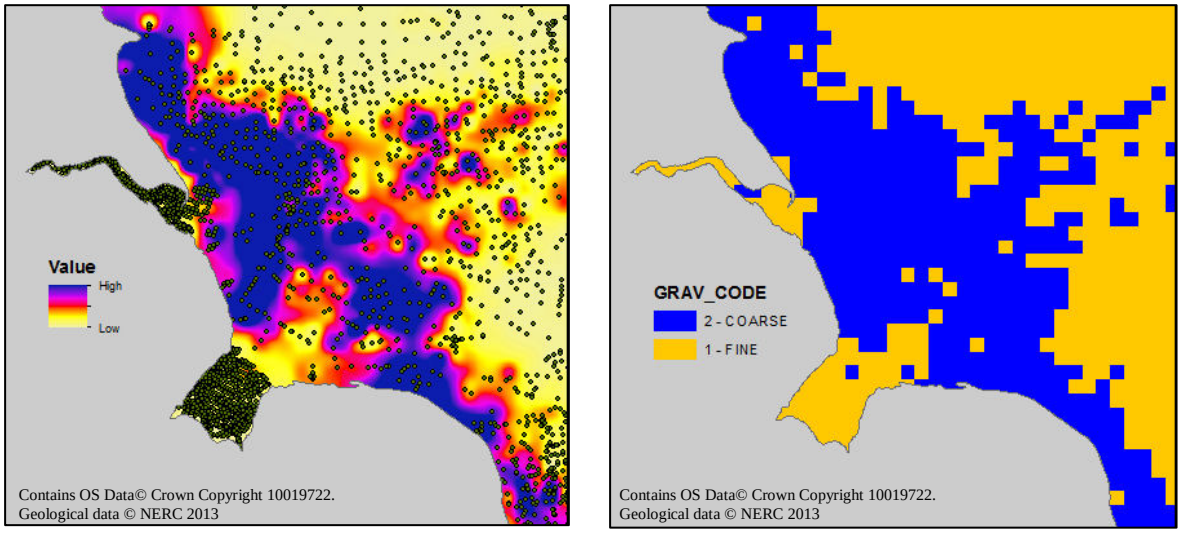

Figure 24: Original interpolation using the IDW technique for the GRAV theme (left) and then reclassified to an appropriate scale (right)

The SAND theme has been classified into the following categories:

SAND_CODE	SAND	SAND2
-999	-999	No Data
1	0 – 39.999%	Low
2	40 – 59.999%	Medium
3	60 – 79.999%	Medium
4	80 – 100%	High

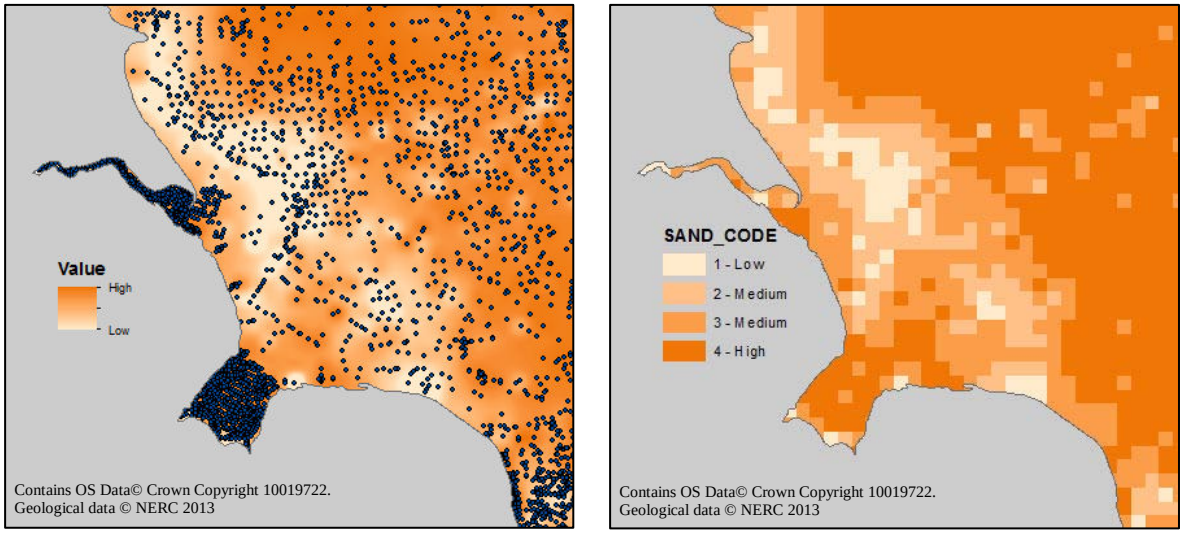

Figure 25: Original interpolation using the IDW technique for the SAND theme (left) and then reclassified to an appropriate scale (right)

The CSAND (carbonate content of sand) theme has been classified into the following categories:

CSAND_CODE	CSAND	CSAND2
-999	-999	No Data
1	20 – 100%	High
2	10 – 19.999%	Medium
3	0 – 9.999 %	Low

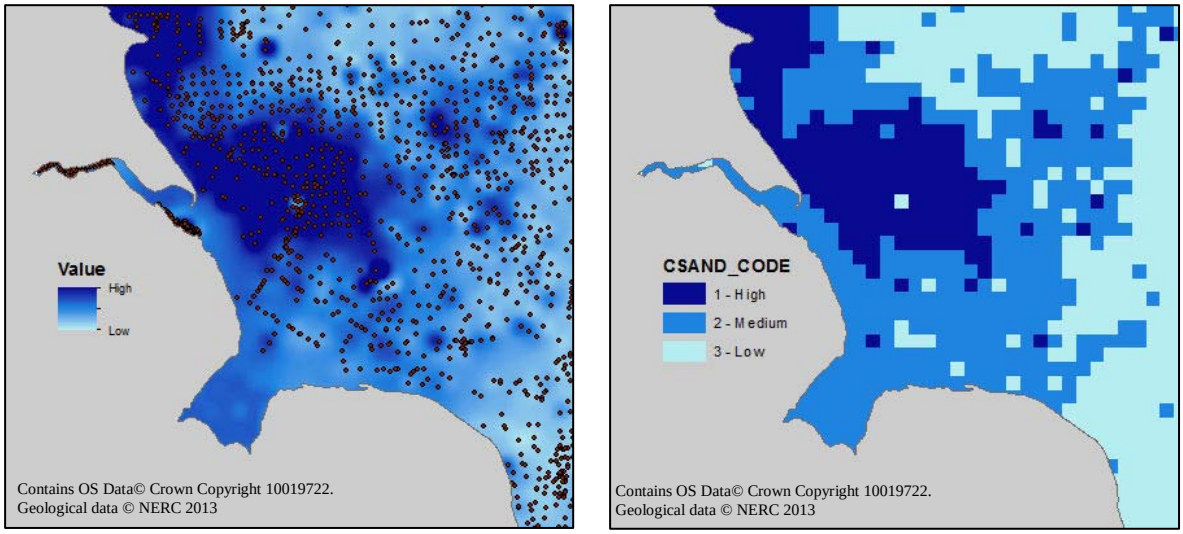

Figure 26: Original interpolation using the IDW technique for the CSAND theme (left) and then reclassified to an appropriate scale (right)

The LGRAV (lithic gravel) theme has been classified into the following categories:

LGRAV_CODE	LGRAV	LGRAV2
-999	-999	No Data
1	0 – 4.999 %	Low
2	5 – 14.999%	Low
3	15 – 49.999%	Medium
4	50 – 100%	High

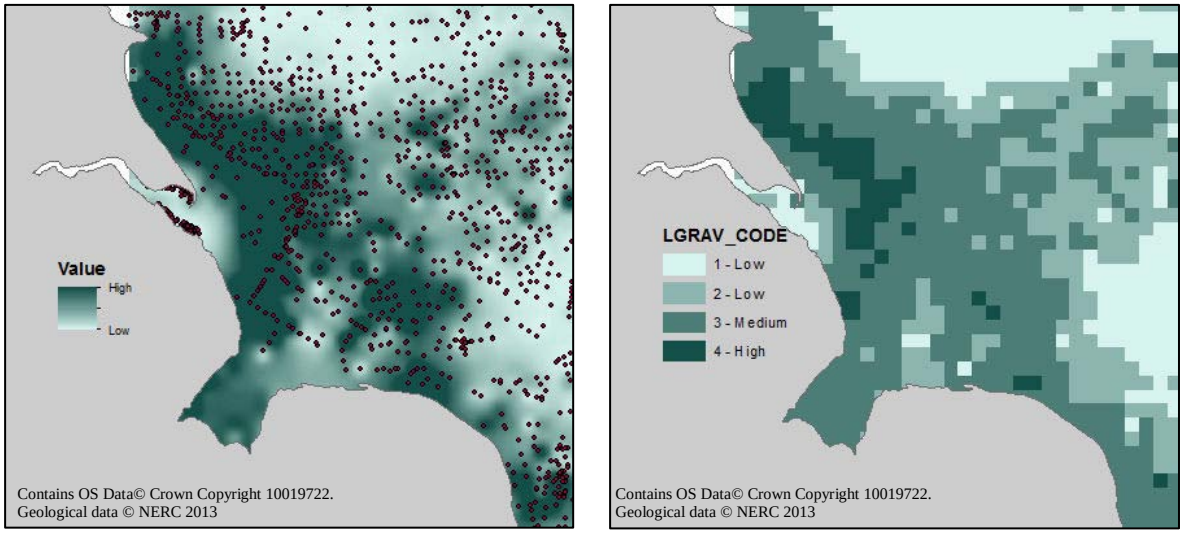

Figure 27: Original interpolation using the IDW technique for the LGRAV theme (left) and then reclassified to an appropriate scale (right).

The CGRAV (carbonate content of gravel) theme has been classified into the following categories:

CGRAV_CODE	CGRAV	CGRAV2
-999	-999	No Data
1	20 – 100%	High
2	10 – 19.999%	Medium
3	0 – 9.999 %	Low

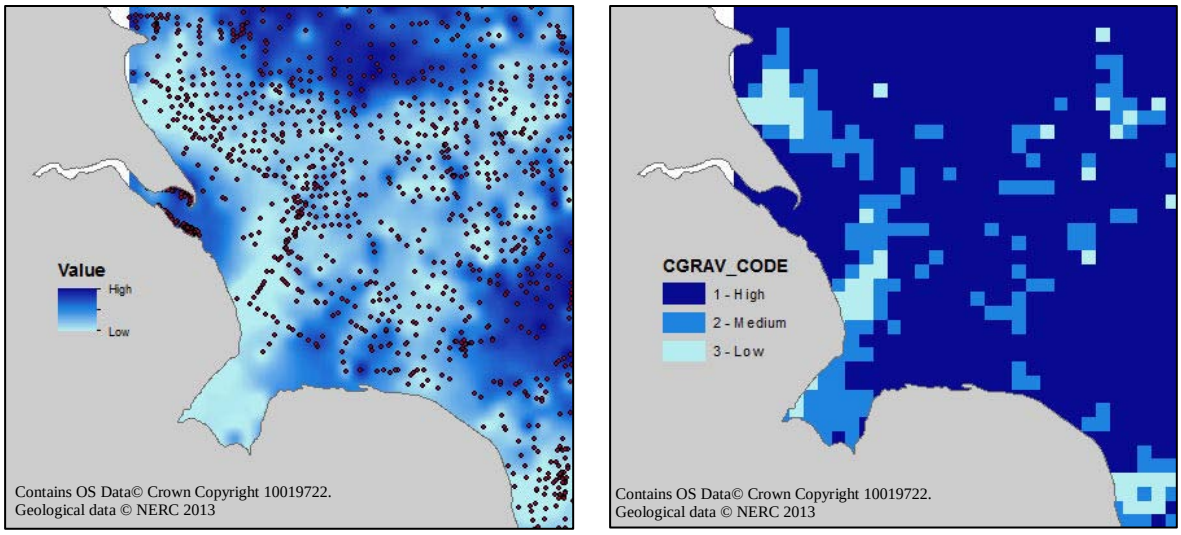

Figure 28: Original interpolation using the IDW technique for the CGRAV theme (left) and then reclassified to an appropriate scale (right)

The model was calculated using ESRI ArcGIS Analysis Overlay Union tool. This tool computes a geometric union of the input features. All features being written to the output feature class with the attributes from the input features, which it overlaps.

All nine themes were used as input features, the resultant output feature class contains the relevant attribution to easily generate resource categories appropriate for the marine aggregate resource map (Figure 29).

The marine aggregate resource map has been classified into the following categories:

RES_CODE	RES_DESC
N	No Resource
F	Aggregate suitable for fill
Cf(f)	Construction Aggregate – Fine (Fine Sand)
Cf(c)	Construction Aggregate – Fine (Coarse Sand)
Cc	Construction Aggregate – Coarse

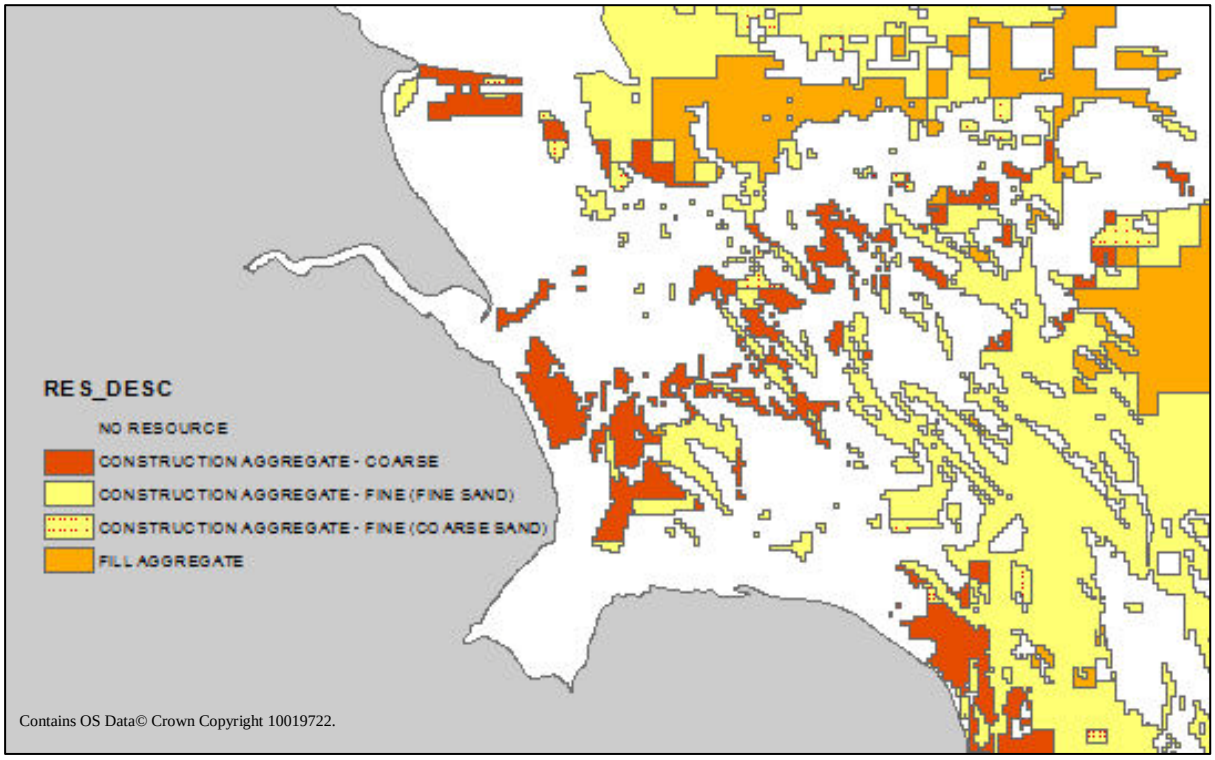

Figure 29: Final marine aggregate resource map

3.4 GEOLOGICAL INTERPRETATION

All outputs produced by the modelling process described in section 3.3 have been reviewed by a geologist and, if appropriate, subsequently modified. This is to ensure that model output matches the known geology and to ensure that the data interpretation process accurately matches known geological and geomorphological features.

This interpretation step involves a review of the model output, incorporating extra bathymetric, geophysical and core data than was possible to include in the data interpolation and integration steps. This may also include input from regional geologists with local knowledge and incorporation of any relevant literature, for example site investigations for renewable energy projects or dredging industry data. A record is made during this stage of any polygons that are modified from the original model output as a result of interpretation by geologists, this is noted in the 'Changed' attribute field.

All polygons categorised as a resource by the modelling process as well as selected non-resource polygons are subjected to a review by a geologist. This review may vary from a brief conformation that a resource polygon fits with the known geology to a detailed analysis of seismic, bathymetric and core records to investigate more complex aggregate bearing geological features. The level of detail of the review will be dependent on the geological complexity of an area and the potential of the area for aggregate resources combined with the level of information available. This review process both serves to truth the results of the modelling process and consider whether the modelling process has missed aggregate resources due to a lack of input data. The most common changes that have been made is to correct for when the surface sediments (where the properties for aggregate resources have been taken from) are not representative of sediment at depth, for instance in areas of thin gravel veneer overlying glacial tills, areas such as these if easily identified if core coverage is sufficient.

This geological review also aids in identifying levels of confidence in the data for specific areas and thus identifies resource categories displayed on the maps as '*areas known to contain important sand and gravel resources*' and '*areas prospective for coarse sand and gravel*' as described in section 3.5.

3.5 DEFINITION OF RESOURCES

The multiple attributes combined within the sand and gravel data modelling process results can be displayed in multiple ways depending on the desired outcome. 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 are based on 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 chart depicting the categorisation of aggregate resources can be seen in Figure 31.

Regionally important aggregate resources are defined as material suitable for contract fill and land reclamation applications. Regionally important resources are based on 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 defined on this map. This is to highlight the large accumulations of biogenic material in some areas which has implications to the use of sediment for aggregate applications. High carbonate sands are considered to be suitable for lower specification applications than those with a high silica content. A limit of 50 per cent has been used as this defines the boundary between a carbonate sediment and a 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. These represent areas where, at a regional scale and using data available to this study, there is no evidence for the presence of 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 map 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. However, some level of differentiation can be applied to areas of inferred mineral resources. Due to geological uncertainty, and variations in the base data used, the following categories, shown in Figure 30, have been used to compile these maps to ensure areas of high quality and economically important minerals are given due consideration.

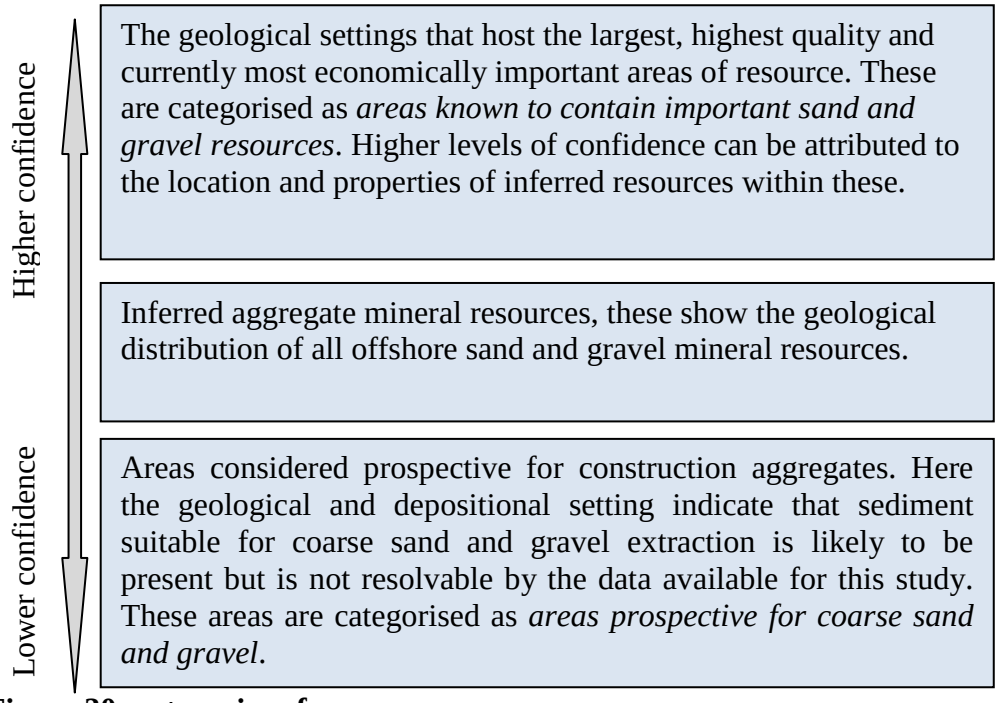

Figure 30: categories of resources

Both the '*areas prospective for coarse sand and gravel'* and '*areas known to contain important sand and gravel resources'* defined in Figure 30 have been created via geological interpretation of known geological and geomorphological formations and features. These can be either a combination of features such as the limit of glacial sediments combined with significant breaks in slope, as is the case in the Humber region, or specific geological formations such as an area of glaciofluvial outwash sediments, as is the case for the Outer Bristol Channel. These areas have defined by a geological interpretation of the model output and the known geology of an area separately to the modelling process used to define all other inferred aggregate resources.

3.5.1 Areas prospective for coarse sand and gravel

These areas relate to geological features (such as palaeochannels or glacial deposits) that may be prospective for sand and gravel but are unresolvable with the current levels of data available to this study. These areas are based on the presence of regional geological formations and features that have been proved to contain economic deposits of sand and gravel in specific localities (i.e. aggregate licence areas). These areas indicate the likely presence of nationally important sand and gravel resources.

3.5.2 Areas known to contain important sand and gravel resources

These give an indication to the location of important aggregate resources. Within these areas, and unlike areas prospective for coarse sand and gravel, a high level of confidence can be attributed to the location and extent of sand and gravel deposits. In addition some economic factors have also been considered, such as distance to markets, to give an indication of what are currently the most important areas of marine sand and gravel resources.

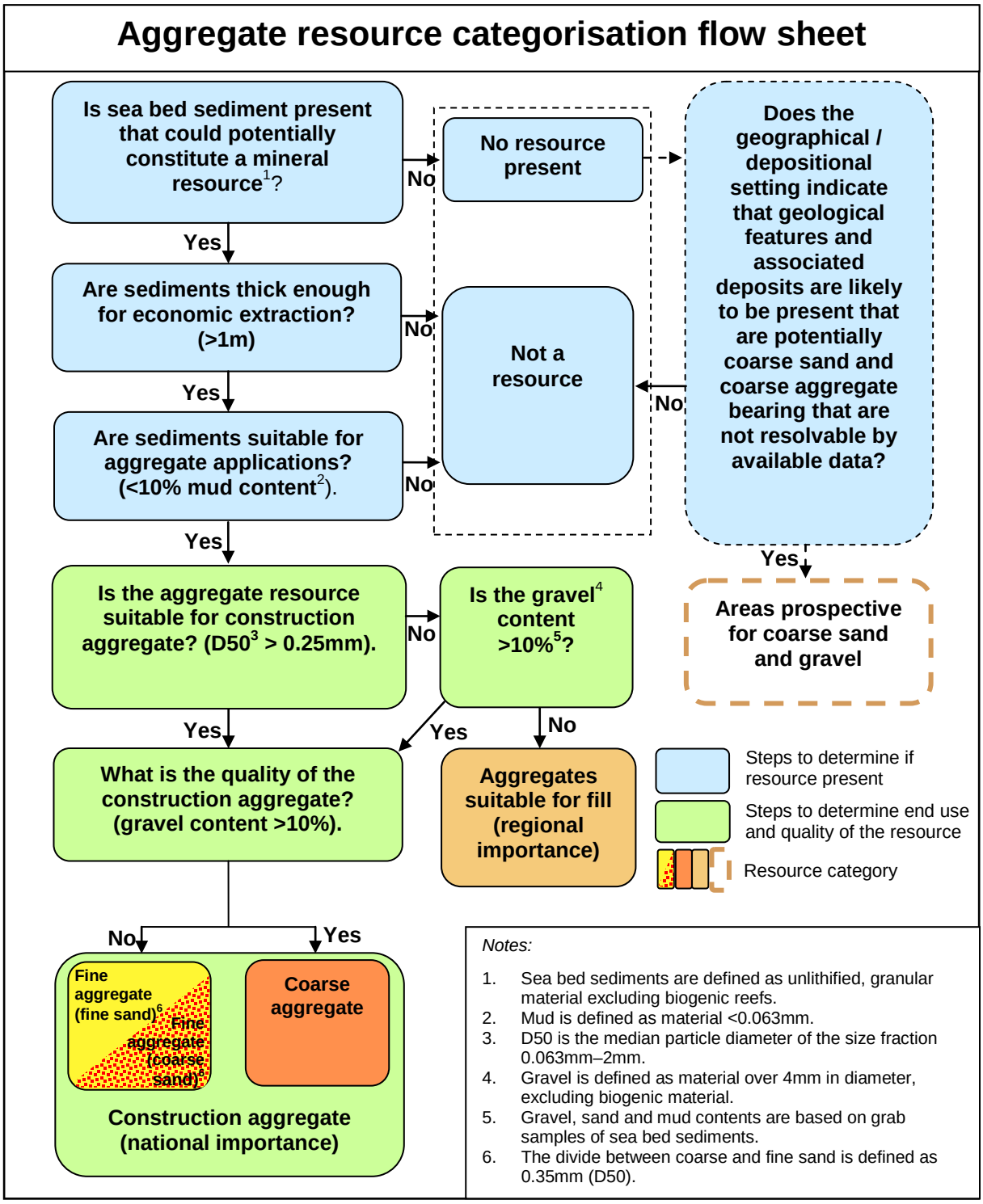

Figure 31: Aggregate resource categorisation flow sheet

3.6 TECHNICAL INFORMATION OF THE MARINE AGGREGATE RESOURCE DATA

3.6.1 Definitions

Section 3.5 documents in detail the definitions of the different resource categories used within this dataset.

3.6.2 Scale

The marine aggregate resource data is produced for use at 1:250 000 scale. This scale data should not be relied on for local or site-specific study, or navigation.

The scale of the original information is indicated by the nominal scale attribute (NOM_SCALE: 250 000) embedded in the data. The data should not be over-enlarged; for example, 1:250 000 nominal scale data should not be used at 1:100 000 or 1:50 000 working scale.

3.6.3 Field Descriptions

Fields in attribute table for final marine aggregate resource map.

Field Name	Field Type	Description
SBS_CODE	SHORT	Sea bed sediment or folk classification codes: -999 No Data 0 No Resource 1 Resource
SBS	TEXT	Sea bed sediment or Folk classification code description: No Data Beyond the coverage of DigSBS250 No Resource Sea bed sediment or Folk classification category indicates no resource present Resource Sea bed sediment or Folk classification category indicates a region of potential resource
MUD_CODE	SHORT	Mud content (as a percentage weight of the sample) codes: -999 No Data 0 No Resource 1 High 2 Low
MUD	TEXT	Mud content code value: -999 No Data 0 10 - 100% 1 5 - 9.999% 2 0 - 4.999%
MUD2	TEXT	Mud content code description: No Data No data available to interpolate No Resource Interpolated data value indicates sediment is not a resource High Interpolated data value (5-9.999%) indicates sediment has a high mud content Low Interpolated data value (0-4.999%) indicates sediment has a low mud content
D50_CODE	SHORT	D50 of the sand fraction codes: -999 No Data 1 Fine and very fine sand 2 Medium fine sand 3 Medium coarse sand 4 Coarse sand 5 Very coarse sand
D50SAND	TEXT	D50 sand code value: -999 No Data 1 4phi (0.063mm) – 2phi (0.25mm) 2 2phi (0.25mm) – 1.5phi (0.35mm) 3 1.5phi (0.35mm) – 1phi (0.5mm) 4 1phi (0.5mm) – 0phi (1.0mm) 5 0ph (1.0mm) – -1phi (2.0mm)

Field Name	Field Type	Description
D50SAND2	TEXT	D50 sand code description: No Data — No data available to interpolate Fine and very fine sand — Interpolated data value indicates the D50 of the sand fraction is within the Wentworth scale range for fine and very fine sand, any potential resource may be suitable as fill aggregate Medium fine sand — Interpolated data value indicates the D50 of the sand fraction is within the Wentworth scale range for medium fine sand, any potential resource may be suitable as construction aggregate Medium coarse sand — Interpolated data value indicates the D50 of the sand fraction is within the Wentworth scale range for medium coarse sand, any potential resource may be suitable as construction aggregate Coarse sand — Interpolated data value indicates the D50 of the sand fraction is within the Wentworth scale range for coarse sand, any potential resource may be suitable as construction aggregate Very coarse sand — Interpolated data value indicates the D50 of the sand fraction is within the Wentworth scale range for very coarse sand, any potential resource may be suitable as construction aggregate
GRAV_CODE	SHORT	Lithic content of the gravel fraction (>4mm) as a percentage of the whole sample codes: -999 No Data 1 Fine 2 Coarse
GRAV	TEXT	Lithic content(>4mm) code value: -999 No Data 1 Gravel (4mm) <10% 2 Gravel (4mm) >10%
GRAV2	TEXT	Lithic content(>4mm) code description: No Data — No data available to interpolate Fine — Interpolated data value indicates that the lithic gravel content (base on a 4mm cut-off) is less than 10%, any potential resource will be suitable as fill aggregate Coarse — Interpolated data value indicates that the lithic gravel content (base on a 4mm cut-off) is greater than 10%, any potential resource will be suitable as construction aggregate
SAND_CODE	SHORT	Sand content (as a percentage weight of the sample) codes: -999 No Data 1 Low 2 Medium 3 Medium 4 High

Field Name	Field Type	Description
SAND	TEXT	Sand content code value: -999 No Data 1 0 – 39.999% 2 40 – 59.999% 3 60 – 79.999% 4 80 – 100%
SAND2	TEXT	Sand content code description: No Data No data available to interpolate Low Interpolated data value (0-39.999%) indicates sediment has a low sand content Medium Interpolated data value (40-79.999%) indicates sediment has a medium sand content High Interpolated data value (80-100%) indicates sediment has a high sand content
CSAND_CODE	SHORT	Carbonate content as a percentage of the sand fraction (Wentworth scale) code: -999 No Data 1 High 2 Medium 3 Low
CSAND	TEXT	Carbonate content (sand fraction) code value: -999 No Data 1 20 – 100% 2 10 – 19.999% 3 0 – 9.999%
CSAND2	TEXT	Carbonate content (sand fraction) code description: No Data No data available to interpolate High Interpolated data value (20-100%) indicates sediment has a high carbonate content within the sand fraction Medium Interpolated data value (10-19.999%) indicates sediment has a medium carbonate content within the sand fraction Low Interpolated data value (0-9.999%) indicates sediment has a low carbonate content within the sand fraction
LGRAV_CODE	SHORT	Lithic content of the gravel fraction (Wentworth scale) as a percentage of the whole sample code: -999 No Data 1 Low 2 Low 3 Medium 4 High
LGRAV	TEXT	Lithic content (gravel fraction) code values: -999 No Data 1 0 – 4.999% 2 5 – 14.999% 3 15 – 49.999% 4 50 – 100%

Field Name	Field Type	Description
LGRAV2	TEXT	Lithic Content (gravel fraction) code description: No Data — No data available to interpolate Low — Interpolated data value (0-14.999%) indicates sediment has a low lithic content within the gravel fraction Medium — Interpolated data value (15-49.999%) indicates sediment has a medium lithic content within the gravel fraction High — Interpolated data value (49.999-100%) indicates sediment has a high lithic content within the gravel fraction
CGRAV_CODE	SHORT	Carbonate content as a percentage of the gravel fraction (Wentworth scale) code: -999 — No Data 1 — High 2 — Medium 3 — Low
CGRAV	TEXT	Carbonate content (gravel fraction) code value: -999 — No Data 1 — 20 – 100% 2 — 10 – 19.999% 3 — 0 – 9.999%
CGRAV2	TEXT	Carbonate content (gravel fraction) code description: No Data — No data available to interpolate High — Interpolated data value (20-100%) indicates sediment has a high carbonate content within the gravel fraction Medium — Interpolated data value (10-19.999%) indicates sediment has a medium carbonate content within the gravel fraction Low — Interpolated data value (0-9.999%) indicates sediment has a low carbonate content within the gravel fraction
THICK_CODE	SHORT	Sediment thickness codes: -999 — No Data 0 — No Resource 1 — Moderate 2 — Thick 3 — Very Thick
THICK	TEXT	Sediment thickness code value: -999 — No Data 0 — 0 – 0.999m 1 — 1 – 1.999m 2 — 2 – 9.999m 3 — >10m
THICK2	TEXT	Sediment thickness code description: No Data — Beyond the coverage of mapped area No Resource — Sediment thickness category indicates not enough sediment present to represent a resource Moderate — Sediment thickness category indicates a region of moderate sediment cover (1 – 1.999m). Thick — Sediment thickness category indicates a region of thick sediment cover (2 – 9.999m) Very Thick — Sediment thickness category indicates a region of very thick sediment cover (>10m)

Field Name	Field Type	Description
RES_CODE	TEXT	Resource codes: N No Resource F Fill Aggregate Cf(f) Construction Aggregate – Fine (Fine Sand) Cf(c) Construction Aggregate – Fine (Coarse Sand) Cc Construction Aggregate – Coarse
RES_DESC	TEXT	Resource code description: N Resource category indicates no resource present F Resource category indicates a region of potential resource suitable for fill aggregate Cf(f) Resource category indicates a region of potential resource suitable for fine (fine sand) construction aggregate Cf(c) Resource category indicates a region of potential resource suitable for fine (coarse sand) construction aggregate Cc Resource category indicates a region of potential resource suitable for coarse construction aggregate
Changed	TEXT	Indicates if the national model output has been modified: Yes The polygon has been reviewed by a geologist and one or more of its properties has been changed based in geological interpretation and/or review of data sources not included in the national model No the polygon is the output of the national model and has not been changed
NOM_SCALE	TEXT	Nominal scale of the published (or compiled) information used to prepare the digital data: e.g.250 000 for 1:250 000
VERSION	DOUBLE	Version of the digital data
RELEASED	DATE	Date released

3.6.4 Creation of the Dataset

A polygon shape file showing areas of marine aggregate resource has been developed using ESRI ArcGIS software. The interpretation was based on a variety of data sourced from within the BGS and open access data supplied by third party organisations. Data consulted includes the BGS 1:250 000 Geological Maps (UTM Series), 1:1 000 000 ancillary maps, BGS Digital Products, archive sample and seismic records, and multibeam bathymetry.

3.6.5 Dataset History

Version1: Released March 2013.

3.6.6 Coverage

Figure 32: The coverage of the marine aggregate resource map

3.6.7 Data Format

The marine aggregate resource map has been created as vector polygons and is available in ESRI ArcGIS (.shp) format.

3.7 TECHNICAL INFORMATION FOR OTHER GIS DATA IN THE MARINE MINERAL RESOURCE OF THE UKCS DATASET

In addition to the marine aggregate resource map additional data has also been produced, supplied as ESRI ArcGIS files, regarding non-aggregate minerals and the locations of important sand and gravel deposits. Information regarding these data are summarised in Table 3.

Name	Scale	Format	Coverage	History
Coal	1: 500 000	vector polygons	UKCS	Version1: Released May 2013
Evaporites	1: 500 000	vector polygons	UKCS	Version1: Released May 2013
Evaporites_limit_of_ halokenetic_deformation	1: 500 000	vector lines	Southern North Sea	Version1: Released May 2013
Metals	1: 500 000	vector points	UKCS	Version1: Released May 2013
Sand_and_gravel_areas_ containing_important_ resources	1: 500 000	vector polygons	England and Wales	Version1: Released May 2013
Sand_and_gravel_areas_ prospective_for_coarse_sand_ and_gravel	1: 500 000	vector polygons	England and Wales	Version1: Released May 2013
Sand_and_gravel_depositional _settings_prospevtive_for_coa rse_sand_and_gravel	1: 500 000	vector polygons	England and Wales	Version1: Released May 2013
Sand_and_gravel_depositional _settings_prospevtive_for_coa rse_sand_and_gravel_lines	1: 500 000	vector lines	England and Wales	Version1: Released May 2013
Sand_where_Carbonate_Conte nt_Exceeds_50percent	1: 250 000	vector polygons	UKCS	Version1: Released May 2013
Mud_content_greater_then_10 percent_prospective_for_fill	1: 500 000	vector polygons	Scotland	Version1: Released June 2013

Table 3: Technical data for additional data to the aggregate resource map supplied with the marine minerals resources of the UKCS dataset

3.7.1 Coal

This dataset contains information on offshore deep coal resources for the UKCS that 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. Information regarding the properties of these offshore coal resources can be found in the relevant report to accompany the map. The coal dataset contains the following fields:

Field name	Field type	Description
MIN_RES	TEXT	The mineral resource present
GEOG_AREA	TEXT	The geographic extent of the coalfield

VERSION	TEXT	Version of the digital data
NOM_SCALE	TEXT	Nominal scale of the published (or compiled) information used to prepare the digital data: e.g.500000 for 1:500 000
RELEASED	DATE	Date released

3.7.2 Evaporites

This dataset contains information on offshore evaporite resources for the UKCS including halite, potash, anhydrite and polyhalite. These resources have been inferred from geological mapping data, a review of relevant literature 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. Information regarding the properties of these offshore evaporite resources can be found in the relevant report to accompany the map. The evaporites dataset contains the following fields:

Field name	Field type	Description
MIN_RES	TEXT	The mineral resource present
MIN_ABBR	TEXT	An abbreviated description of the generic type of mineral resource and the formation or basin in which it occurs
LABEL	TEXT	The text used to display on maps contained within the regional reports
VERSION	TEXT	Version of the digital data
NOM_SCALE	TEXT	Nominal scale of the published (or compiled) information used to prepare the digital data: e.g.500000 for 1:500 000
RELEASED	DATE	Date released

3.7.3 Evaporites_limit_of_halokenetic_deformation

This dataset contains information on the limit of halokenetic deformation in the southern North Sea due to the formation of salt diapirs. This has been inferred from geological mapping data and a review of relevant literature. Information regarding this feature can be found in the relevant report to accompany the map. The Evaporites_limit_of_halokenetic_deformation dataset contains the following fields:

Field name	Field type	Description
MIN_RES	TEXT	The mineral resource present
FEATURE	TEXT	A description of the feature present in the dataset
VERSION	TEXT	Version of the digital data

NOM_SCALE	TEXT	Nominal scale of the published (or compiled) information used to prepare the digital data: e.g.500000 for 1:500 000
RELEASED	DATE	Date released

3.7.4 Metals

This dataset contains information on significant offshore occurrences of metallic minerals for the UKCS. The minerals considered are manganese, magnetite, chromite, zircon and cassiterite, other metallic minerals may be present on the UKCS but have not been recorded in significant concentrations. Data have been inferred from geological mapping data, a review of relevant literature and the interpretation geochemical information. These resources have not been evaluated on any systematic basis by drilling or by other sampling methods for the purpose of mineral exploration. Information regarding the properties of these offshore metallic mineral resources can be found in the relevant report to accompany the map. The metals dataset contains the following fields:

Field name	Field type	Description
MIN_RES	TEXT	The mineral resource present
MIN_ABBR	TEXT	An abbreviated description of the generic type of mineral resource
VERSION	TEXT	Version of the digital data
NOM_SCALE	TEXT	Nominal scale of the published (or compiled) information used to prepare the digital data: e.g.500000 for 1:500 000
RELEASED	DATE	Date released

3.7.5 Sand_and_gravel_areas_containing_important_resources

This dataset contains information on the location of important aggregate resources within which a high level of confidence can be attributed to the location and extent of sand and gravel deposits. These resources have been inferred from geological mapping data, a review of relevant literature and the interpretation of cores. These resources have not been evaluated on any systematic basis on a regional scale by drilling or by other sampling methods for the purpose of mineral exploration. Information regarding the properties locations and methodology used to define these areas can be found in the relevant report to accompany the map. The sand_and_gravel_areas_containing_important_resources dataset contains the following fields:

Field name	Field type	Description
MIN_RES	TEXT	The mineral resource present
MIN_ABBR	TEXT	An abbreviated description of the generic type of mineral resource and the geological environment in which it is

		hosted
VERSION	TEXT	Version of the digital data
NOM_SCALE	TEXT	Nominal scale of the published (or compiled) information used to prepare the digital data: e.g.500000 for 1:500 000
RELEASED	DATE	Date released

3.7.6 Sand_and_gravel_areas_prospective_for_coarse_sand_and_gravel

This dataset contains information on the location areas prospective for coarse sand and gravel. These areas relate to geological features (such as palaeochannels or glacial deposits) that may be prospective for sand and gravel but are unresolvable with the current levels of data available to this study. These areas are based on the presence of regional geological formations and features that have been proved to contain economic deposits of sand and gravel in specific localities. These resources have been inferred from geological mapping data, a review of relevant literature and the interpretation of cores. These resources have not been evaluated on any systematic basis on a regional scale by drilling or by other sampling methods for the purpose of mineral exploration. Information regarding the properties locations and methodology used to define these areas can be found in the relevant report to accompany the map The Sand_and_gravel_areas_prospective_for_coarse_sand_and_gravel dataset contains the following fields:

Field name	Field type	Description
MIN_RES	TEXT	The mineral resource present
MIN_ABBR	TEXT	An abbreviated description of the generic type of mineral resource and the geological environment in which it is hosted
VERSION	TEXT	Version of the digital data
NOM_SCALE	TEXT	Nominal scale of the published (or compiled) information used to prepare the digital data: e.g.500000 for 1:500 000
RELEASED	DATE	Date released

3.7.7 Sand_and_gravel_depositional_settings_prospective_for_coarse_sand_and_ gravel

This dataset contains information on the depositional settings used to define the areas prospective for coarse sand and gravel. These areas represent regional geological formations and features that have been proved to contain economic deposits of sand and gravel in specific localities. These resources have been inferred from geological mapping data, a review of relevant literature and the interpretation of cores. These resources have not been evaluated on any systematic basis on a regional scale by drilling or by other sampling methods for the purpose of mineral exploration. Information regarding the properties locations and methodology used to define these areas can be found in the relevant report to accompany the map. The

Sand_and_gravel_depositional_settings_prospective_for_coarse_sand_and_gravel dataset contains the following fields:

Field name	Field type	Description
MIN_RES	TEXT	The mineral resource present
MIN_ABBR	TEXT	An abbreviated description of the geological setting with potential to host aggregated resources
VERSION	TEXT	Version of the digital data
NOM_SCALE	TEXT	Nominal scale of the published (or compiled) information used to prepare the digital data: e.g.500000 for 1:500 000
RELEASED	DATE	Date released

3.7.8 Sand_and_gravel_depositional_settings_prospective_for_coarse_sand_and_gravel_lines

This dataset contains the same information as that described in section 3.7.7 but represented as line features, not polygons.

3.7.9 Sand_where_carbonate_content_exceeds_50percent

This dataset contains information on areas where the carbonate content of the sand fraction for any marine aggregate resources which is within the sand fraction (coarse sand, fine sand and aggregate suitable for fill) has a carbonate content of over 50%. The dataset has been extracted directly from marine aggregate resource map, and is based on sea bed sediment samples. The Sand_where_carbonate_content_exceeds_50percent dataset contains the following fields:

Field name	Field type	Description
CAT	TEXT	A description of the feature
VERSION	TEXT	Version of the digital data
NOM_SCALE	TEXT	Nominal scale of the published (or compiled) information used to prepare the digital data: e.g.500000 for 1:500 000
RELEASED	DATE	Date released

3.7.10 Mud_content_greater_then_10percent_prospective_for_fill

This dataset contains information on areas around the Scottish coast where areas of potential resources has been identified for land reclamation and fill applications, however mud contents are high (over 10%) so these potential resources do not fit into the existing resource classification. These polygons are defined on the bases the presence of sandy sediment over 1m thick. The Mud_content_greater_then_10percent_prospective_for_fill dataset contains the following fields:

Field name	Field type	Description
CAT	TEXT	A description of the feature
VERSION	TEXT	Version of the digital data
NOM_SCALE	TEXT	Nominal scale of the published (or compiled) information used to prepare the digital data: e.g.500000 for 1:500 000
RELEASED	DATE	Date released

3.8 CONVERSION OF GRAVEL FRACTION TO MEET EUROPEAN STANDARDS

3.8.1 Introduction

One major issue in the definition of offshore aggregate resources based on existing BGS data is mapping sediment definitions from geological classification schemes to those used by the aggregate industry. BGS sediment grain size data are categorised according to the Wentworth Scale. This defines gravel as over 2 mm (-1 phi). However, gravel is defined by particles over 4 mm (-2 phi) by the aggregate industry and in European Standards. For this project, for samples where no data were collected for sieves over 2 mm (-1 phi) statistical methods were used to interpolate the quantity of material in the gravel fraction according to the European Standard.

Sediment grain size data held by BGS is typically sieved at either half phi or phi intervals between 4 (63 micron) and -1 phi (2mm) (the sand fraction as defined by the Wentworth classification scheme). For the calculation of the industry standard gravel fraction the -1 to -2 phi fraction must also be known. This missing fraction has been predicted for this study based on the distribution of sediment in the -1 – 0 phi, 0 – 1 phi 1 – 2 phi 2 – 3 phi and 3 – 4 phi particle size ranges. It is assumed that the distribution of sediment particle size follows predicable patterns i.e. a muddy sediment will have a positively skewed normal distribution with a median towards fine sand whereas a well sorted sand from a sand bank may have a normal distribution with a median in the medium sand fraction.

A statistical model was developed in which the -1 – 4 phi particle size ranges were used as predictor variables for the gravel fraction (the dependant variable). There are a number of ways that the statistical model can be established; in this instance it was decided to use a simple linear model with the gravel fraction being predicted from the sum of the predictor variables multiplied by suitable coefficients. Since there is likely to be a high degree of correlation between the predictor variable, as the mass of sediment in a particle sieve size is likely to be strongly related to that in adjacent sieve sizes, normal linear regression is unsuitable. As a result partial least squares regression (PLS) was chosen as the method of choice and works well with correlated data (Geladi and Kowalski, 1986).

3.8.2 Initial data exploration

Data manipulations and statistical modelling was carried out using the R programming language (R Development Core Team, 2012).

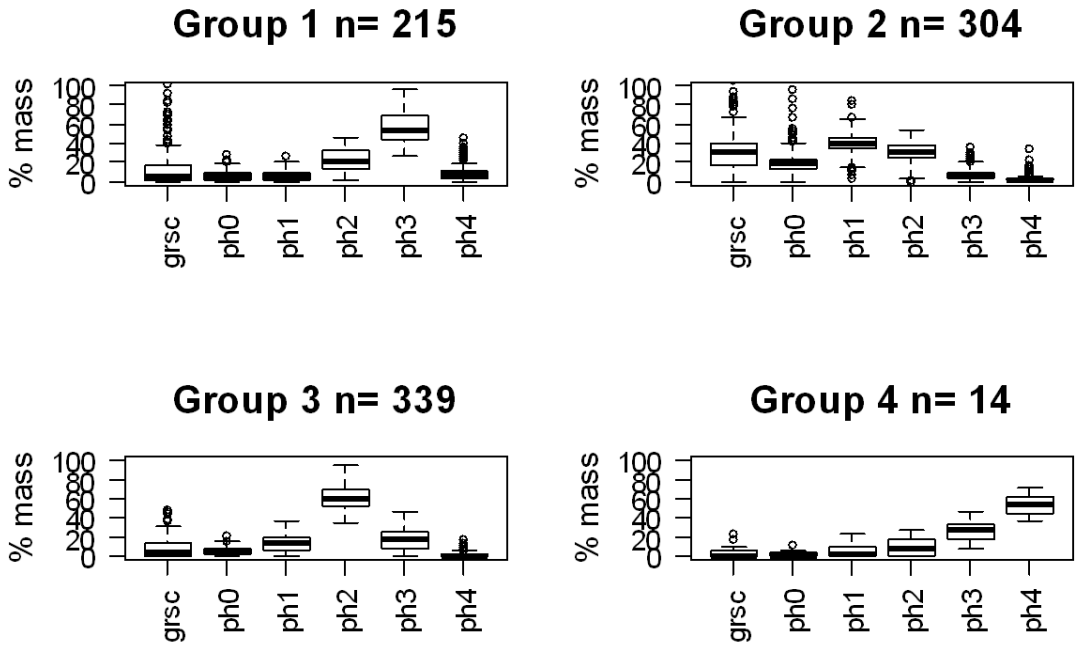

Figure 1: Cluster groupings identified within the training data (grsc = industry standard gravel fraction)

To make the dataset consistent half phi data were converted to whole phi data. A training set was created from data where the sediment sample had been sieved at a much larger range of intervals than had been used for standard BGS particle size analysis, typically from 8 to -10 phi (very fine silt to boulders according to Wentworth size classes) these data were taken from Regional Environment Characterisation Study areas. This training set can be used to show the relationships of different phi intervals and thus calculate values in the prediction dataset where the gravel fraction is missing and needs to be predicted. The distribution of particle size is related to the mode of sediment deposition and the type of sediment present therefore it was unlikely to be the same for all samples. The combined training and prediction set was subjected to a clustering algorithm in the flexible procedures for clustering package (fpc) of the R programming language called Partitioning around medoids with estimation of number of clusters, a robust method for identifying clusters in multivariable data. The resulting analysis showed the presence of four clusters, representing the most common sediment types, the distribution of the data within these four clusters for the training datasets along with the known gravel fractions is shown in boxplots in Figure 33.

1.1.1 Data modelling

A PLS model was set up for each of the four clusters and one for the whole training dataset. Table 4 gives summary of data for the five models. The final column gives the root mean square error of prediction (RMSEP) for each model. Since there are very few data points in the cluster 4 data model predictions for this cluster were performed using the model for all of the data.

Cluster	Points in Training set	Optimum number of PLS components	RMSEP %
1	215	4	10.5
2	304	1	17.6
3	339	3	6.5
4	14	1	7.3
All	872	3	13.2

Table 4: Summary of data for the five models

3.8.4 Data predictions

The -1 to -2 phi fraction for the UKCS were predicted by first classifying the samples into appropriate cluster classes based on their 0-4 phi distributions and then using the appropriate PLS model outlined in Table 1. Once the new phi interval had been predicted it was subtracted from the total Wentworth gravel weight and added to the total Wentworth sand weight thus converting the gravel fraction from >-1 phi to >-2 phi making the data comply with European Standards for aggregates and resulting in an output much more relevant to the aggregates industry.

3.8.5 Limitations on Data Predictions

Whilst visual inspection of the data through spatial plots suggests that the predictions are consistent with the rest of the dataset, the overall quality of the dataset depends on whether the training data are representative of the data points to be predicted. The training dataset is relatively small and localized, being compiled from suitable data from the REC reports, compared to the coverage of the data to be predicted (particularly in Scotland where no training dataset was available and the predictions are base on samples from England). Ideally a range of training sets from specific geological terrains should be used and matched to the geology in areas for which values are being predicted. Also this method will produce poor results in samples with a bimodal distribution or where the majority of the mass of the sample is in the values being predicted. Further work is required to optimize the modelling process to understand the accuracy and uncertainties on the predicted values.

4 Confidence

In addition to the production of the marine aggregate resource map, a map of the associated level of confidence has been determined. Confidence was explored using two distinct methods; one attempts to visualise the influence of sample density, depth and sediment variability in interpolated data, whilst the other is based on broad assessment of interpreted polygon confidence. The resultant two grids are combined to produce a single grid of confidence.

It is important to stress that this is only an approximate visualisation of confidence. Although the latter method attempts to assess qualitative factors, it cannot fully take into account the various levels of expertise brought to the marine aggregate resource map by the individual geoscientists involved. The grid does not have any 'real' numerical values attached – it is simply low to higher confidence.

4.1 SAMPLE GRID

The sample confidence grid is based on the combination of a number of individual grids to create a single score, from low to higher confidence. A score for sample density is calculated and combined with several factors that attempt to indicate possible sediment variability experienced at a location that could have a negative effect on confidence. These include the creation of depth zones and finding the variety of different sediment samples within a specified area.

4.1.1 Sample density

Sample density is calculated using ESRI ArcGIS Spatial Analyst Point Density tool. A neighbourhood is defined around each cell centre and the number of points that fall within the search neighbourhood is totalled and divided by the area of neighbourhood. A search area with a radius of 10km was deemed appropriate for the map (Figure 34). The initial step was to calculate density for samples with GSM (gravel, sand and mud percentage) analysis only. The resulting density calculations were reclassified to assign an appropriate score for inclusion in the final sample confidence grid (Figure 35).

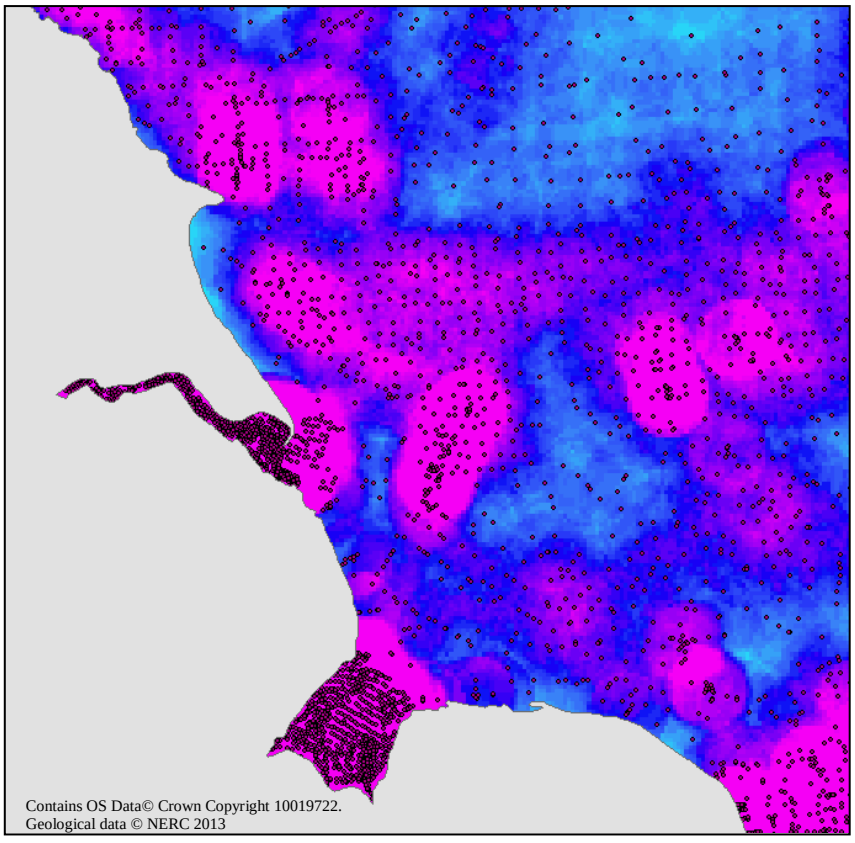

Figure 34: Samples with GSM analysis:

10km search radius.

Search area - 314km2

SCORES:

> 20 samples (0.06) = 3

10-20 samples (0.03) = 2

1-10 samples = 1

No samples = No data

The grid was then generalised to remove the finer detail that could confuse the confidence visualisation and make combination with additional datasets less effective for a 1:250 000 map product (Figure 35– DEN-GSM). The same process was repeated for samples with full particle size analysis (Figure 36– DEN-PHI).

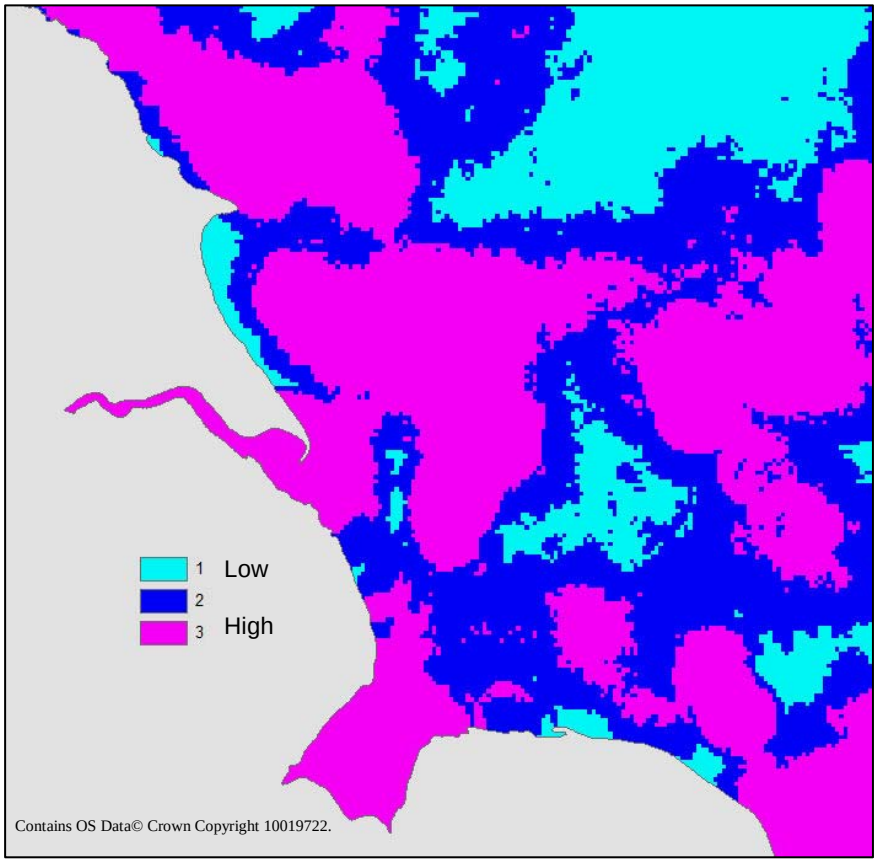

Figure 35: Generalised and reclassified GSM density grid (DEN-GSM - for values see Figure 34)

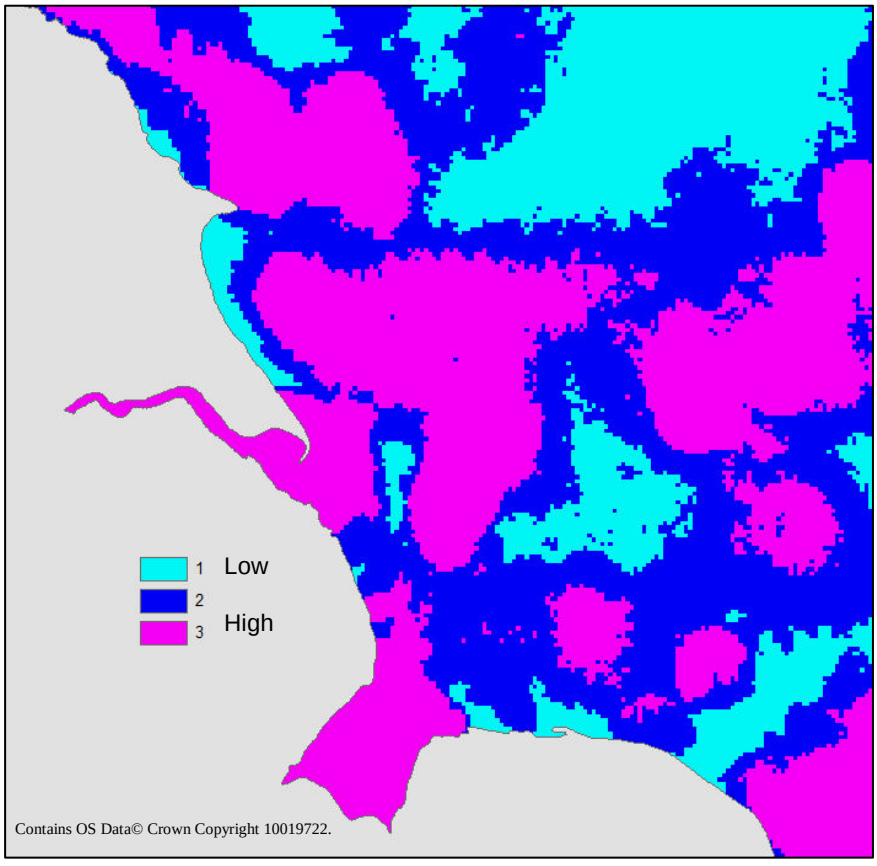

Figure 36: Sample density for samples with full particle size analysis (DEN-PHI). For values see Figure 34)

4.1.2 Depth Zones

Sediments in very deep water will have less variability, yet there will be fewer samples to assign any confidence value. The confidence in interpretation is high in these deeper areas, as opposed to a shallow area of higher energy and variability, yet larger number of samples. A grid of 3 depth zones was created to make some allowance for this factor (Figure 37). This was generated from DigBath250 and delineates to three distinct regions 0-35 m, 35-500 m, >500 m. When combined with the sample density grids areas below 35 m water depth are deducted a point, whilst >500 m gain a point of confidence.

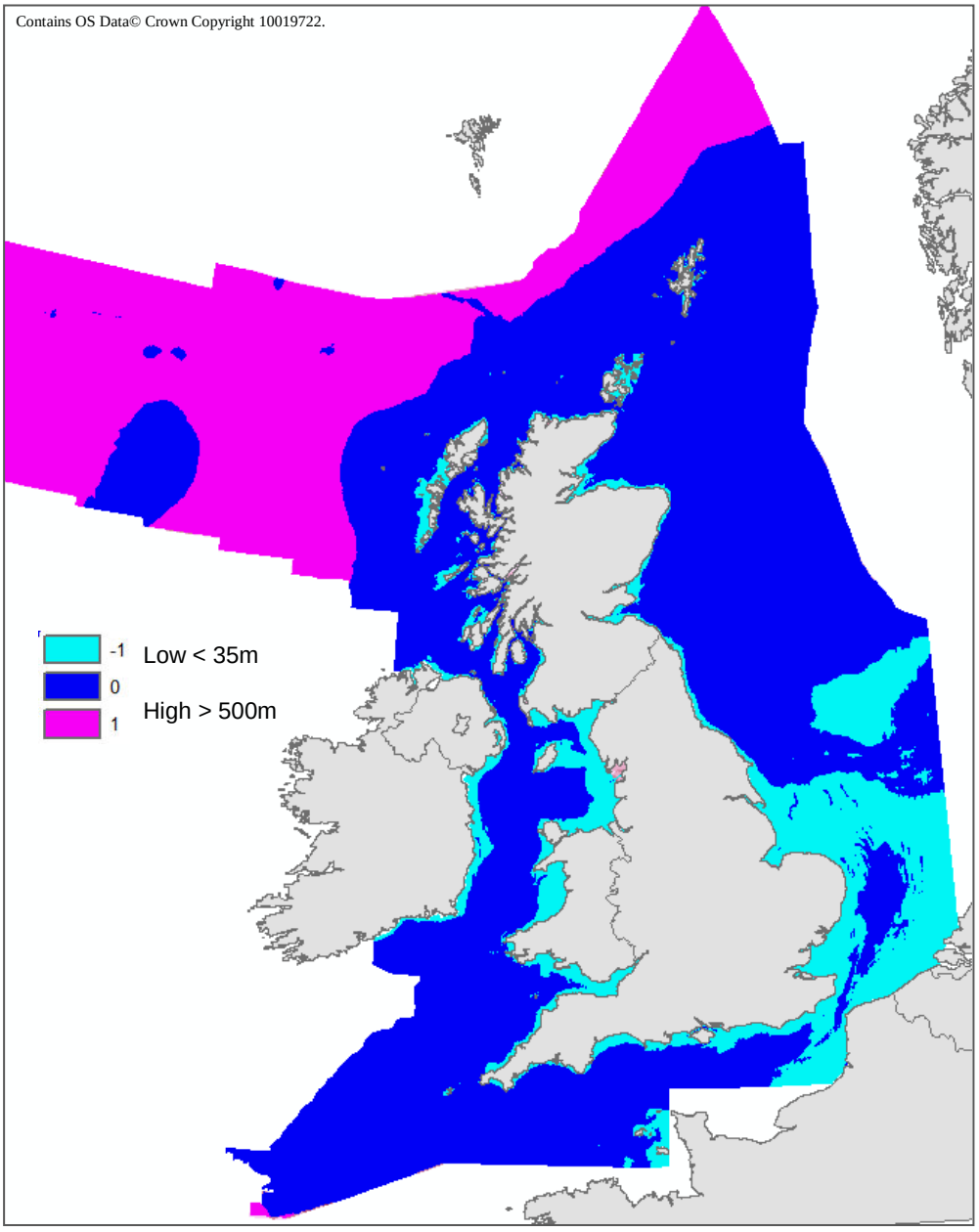

Figure 37: Depth zones (DEPTH)

4.1.3 Sediment Variability

The Point Statistics function of ArcGIS spatial analyst was used to examine the amount of variety seen in sediment samples within a specified search area (314 km^2). Each unique occurrence of a Folk classification was identified; this grid highlights areas of expected high sediment variability. The grid was then reclassified to keep within the three point scoring system (Figure 38 SBS-VAR).

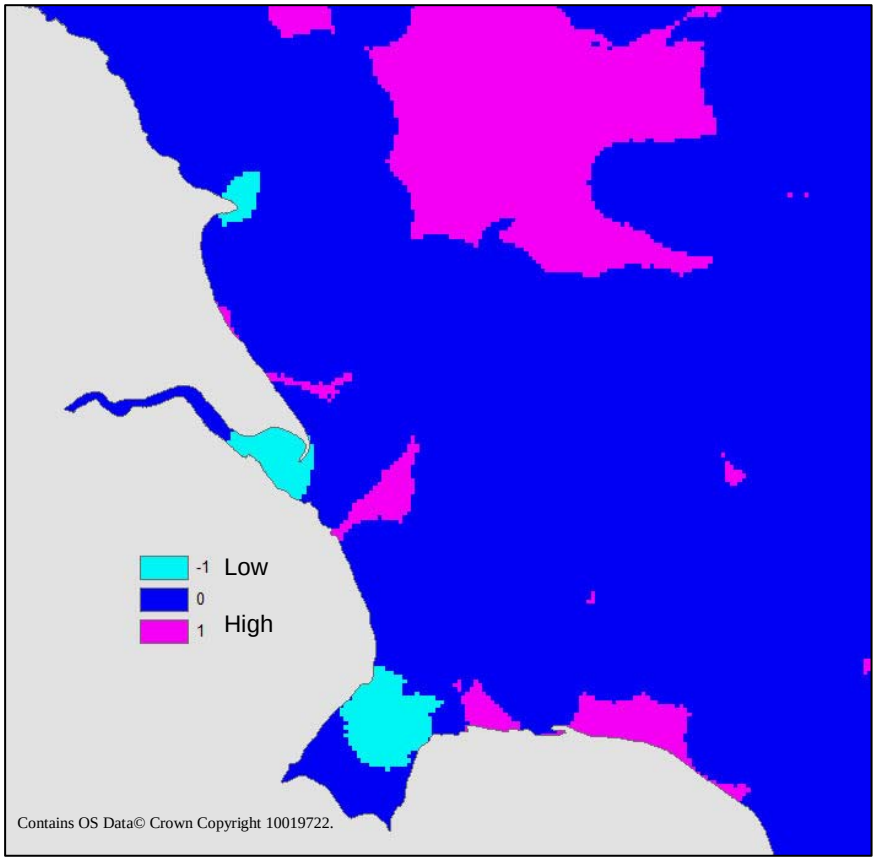

Figure 38: Point statistics highlights sediment variability in expected places (SBS-VAR).

(2 folk class within 314 km^2 = 1, 3-8 = 0, >8 = -1)

4.1.4 Sample Grid Calculation

Raster Calculator was used to add all the grids together (DEN-GSM + DEN-PHI + DEPTH + SBS-VAR). Where there are no samples on which to base an original scoring on the DEN-GSM or DEN-PHI grids, then no data has been assigned. Within the final sample confidence grid, areas of no data are then converted to a score of zero, to maintain a continuous visualisation of confidence. The actual final score value is irrelevant as it is just a low to higher level of confidence based upon sample density, variability and depth (Figure 39). The process is repeatable and is totally independent of any individual bias or subjectivity in assessing confidence.

The values of the grid can be changed proportionately to fit the application of end user.

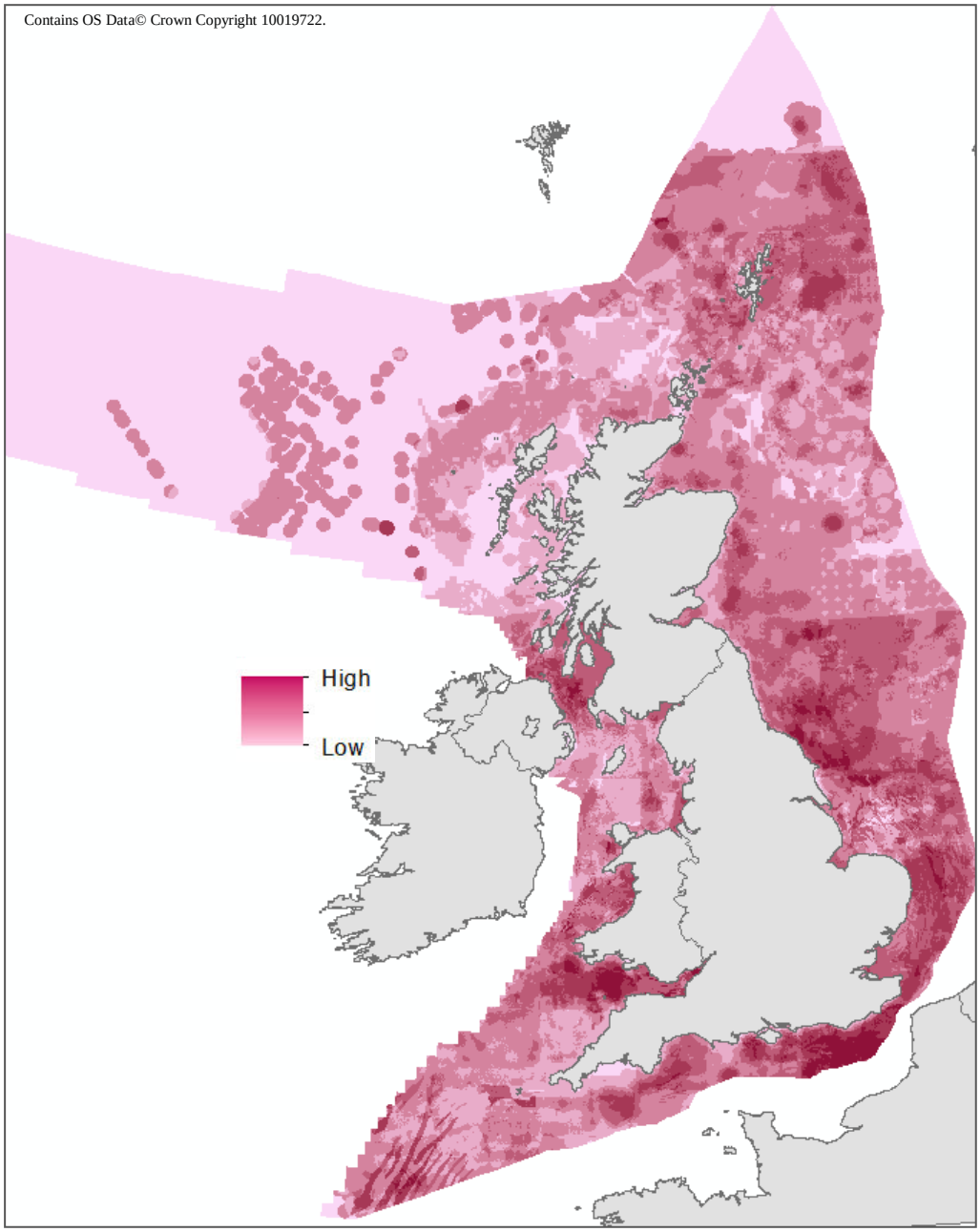

Figure 39: Final sample confidence grid

4.2 INTERPRETATION GRID

The interpretation confidence assessment is based on a qualitative review of the data rather than a quantitative review. It aims to assess a number of qualitative factors that could have a positive or negative effect on the final interpreted polygons. This grid is designed to be combined with the sample grid, as it is based primarily on an assessment of the marine aggregate resource map, a direct output of the modelled sample data.

A positive, neutral or negative score is calculated for several influencing factors. These include an assessment of the quality of the sediment thickness coverage, a geoscientific assessment of the marine aggregate resource map, plus the positive influence of areas containing important sand and gravel resources and the negative influence of areas prospective for sand and gravel, which are not resolved by the available data.

4.2.1 Sediment Thickness

Sediment thickness is based on a number of data sources (section 2.1.3 and section 2.1.4), the vintage and quality of these disparate data sources will have an impact on the confidence. The BGS 1:1 000 000 ancillary maps showing the thickness of Holocene sediments are variable in age and quality, in some areas they will increase confidence, in others they will make no difference to confidence. However, where various bedforms have been mapped by interpretation of borehole, acoustic seismic or multibeam data confidence is higher. A grid of 3 scenarios, interpreted bedforms, ancillary maps and no thickness data, was created to make allowance of this factor (Figure 40). This was generated from the sediment thickness theme and defines the 3 distinct scenarios, where interpreted bedforms are present there is a positive influence on confidence, and where there is no data relating to sediment thickness there is a negative influence on confidence. The presence of ancillary maps is classed as having neither a positive nor negative influence due to their variability.

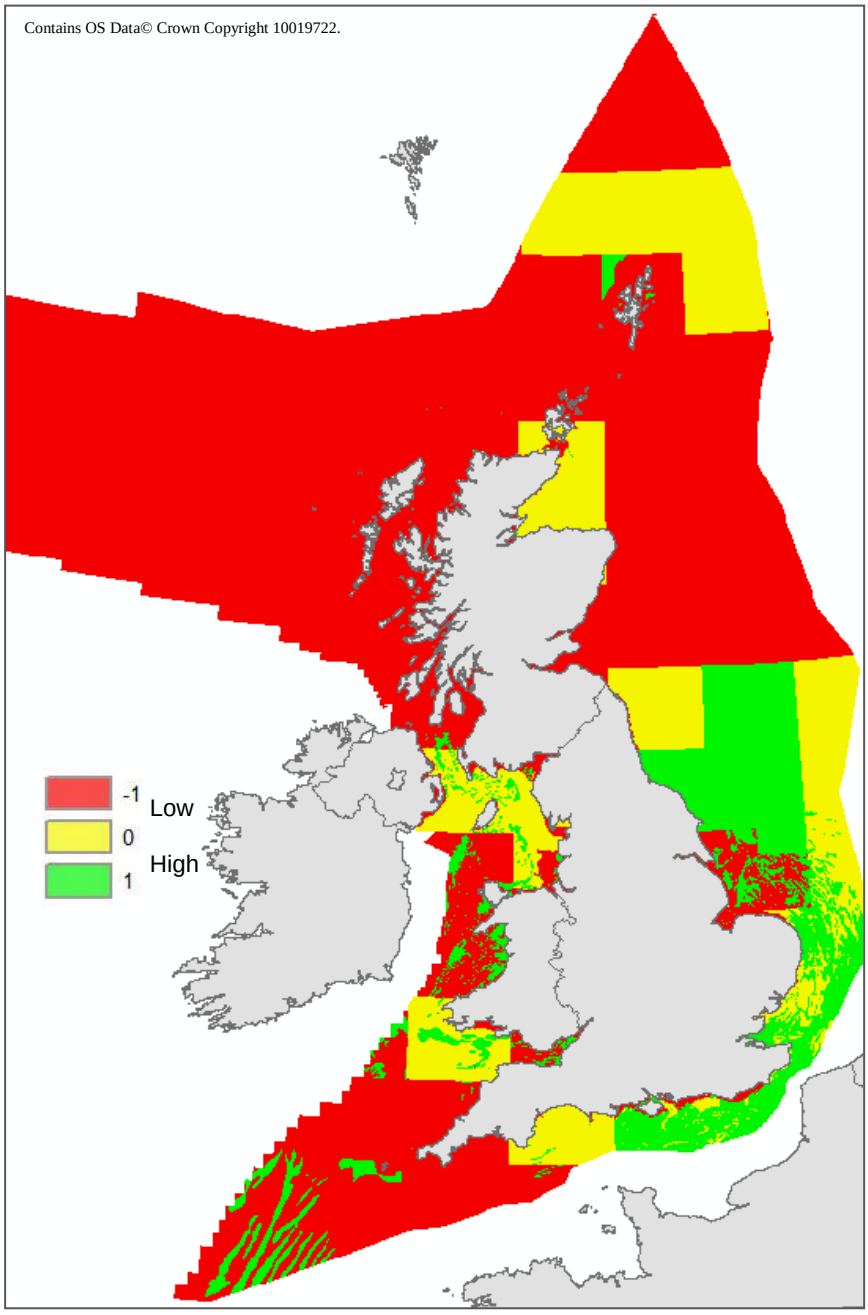

Figure 40: Impact of sediment thickness data (SED-THK)

4.2.2 Geoscientific Assessment

Not every polygon within the marine aggregate resource map has been assessed by a resource geologist. This was deemed to be a too large and time-consuming task, however all polygons classed as a resource have been checked and either accepted or modified by an appropriate specialist. In addition, some areas classed as no resource have also been checked and again, either accepted, or modified to a resource category, mainly where there was little or no data coverage in an area known to be prospective for sand and gravel resources. It should also be noted that supplemental data supplied by The Crown Estate after completion of the data interpolation and modelling phase has been used to ground truth limited areas. A simple grid was created to take into account polygons checked, and accepted to be correctly categorised, or checked and modified to a different category based on expert knowledge or ground truthing. A polygon that has not been assessed will have neither a positive nor negative influence on confidence. This grid was generated by assigning a positive value where a polygon has been checked and a neutral value to all other areas (Figure 41).

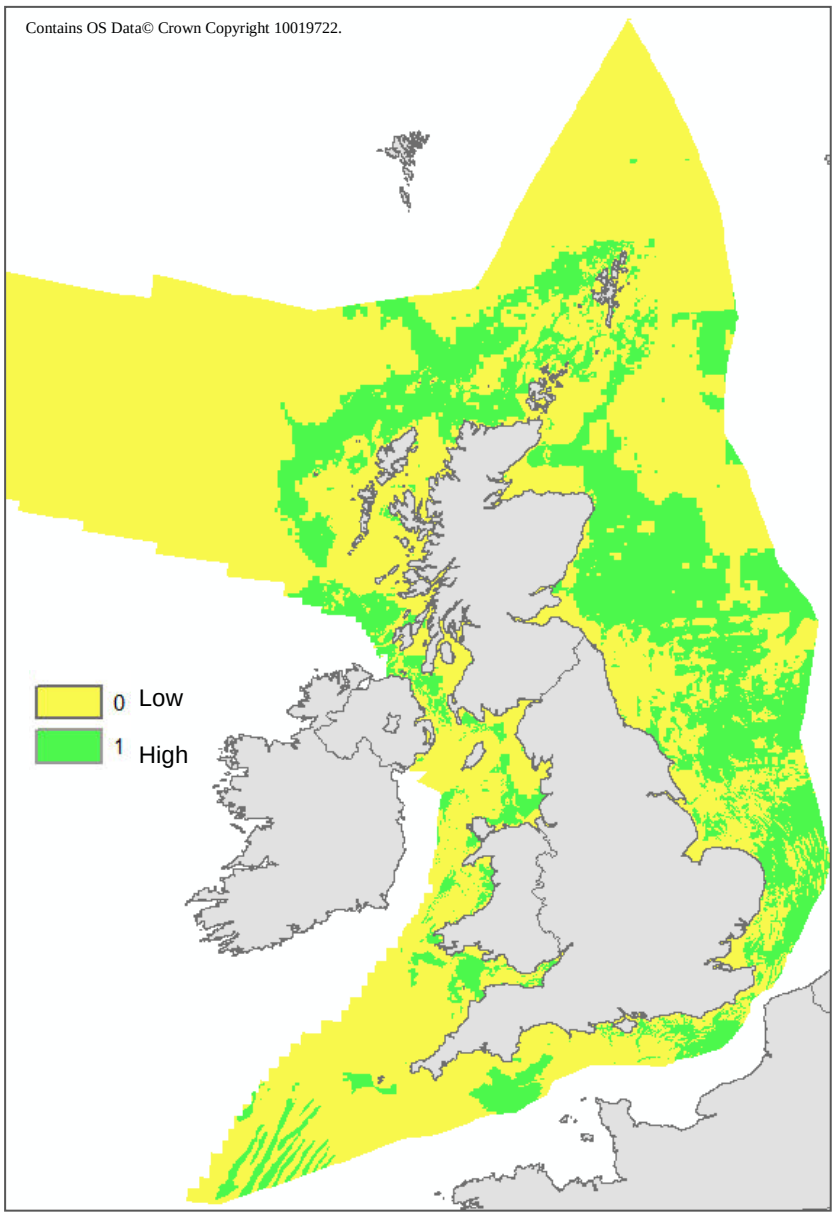

Figure 41: Simple grid depicting polygons checked by a resource geologist (GEOSCI)

4.2.3 Areas Containing Important Resources

These areas represent geological environments that host the largest, highest quality and currently most economically important areas of sand and gravel resources. A high level of confidence can be attributed to the location and properties of resources in these areas.

4.2.4 Areas Prospective for Resources

In these areas the geological and depositional setting indicate that sediments suitable for coarse sand and gravel are likely to be present but are not resolved by the data available for this study. The prospective areas denote areas where aggregate is known to be present but confidence on its precise location is low.

Areas containing important sand and gravel resources have a positive influence on confidence, whereas areas prospective for resources have a negative influence, all other areas can be assigned a neutral value (Figure 42).

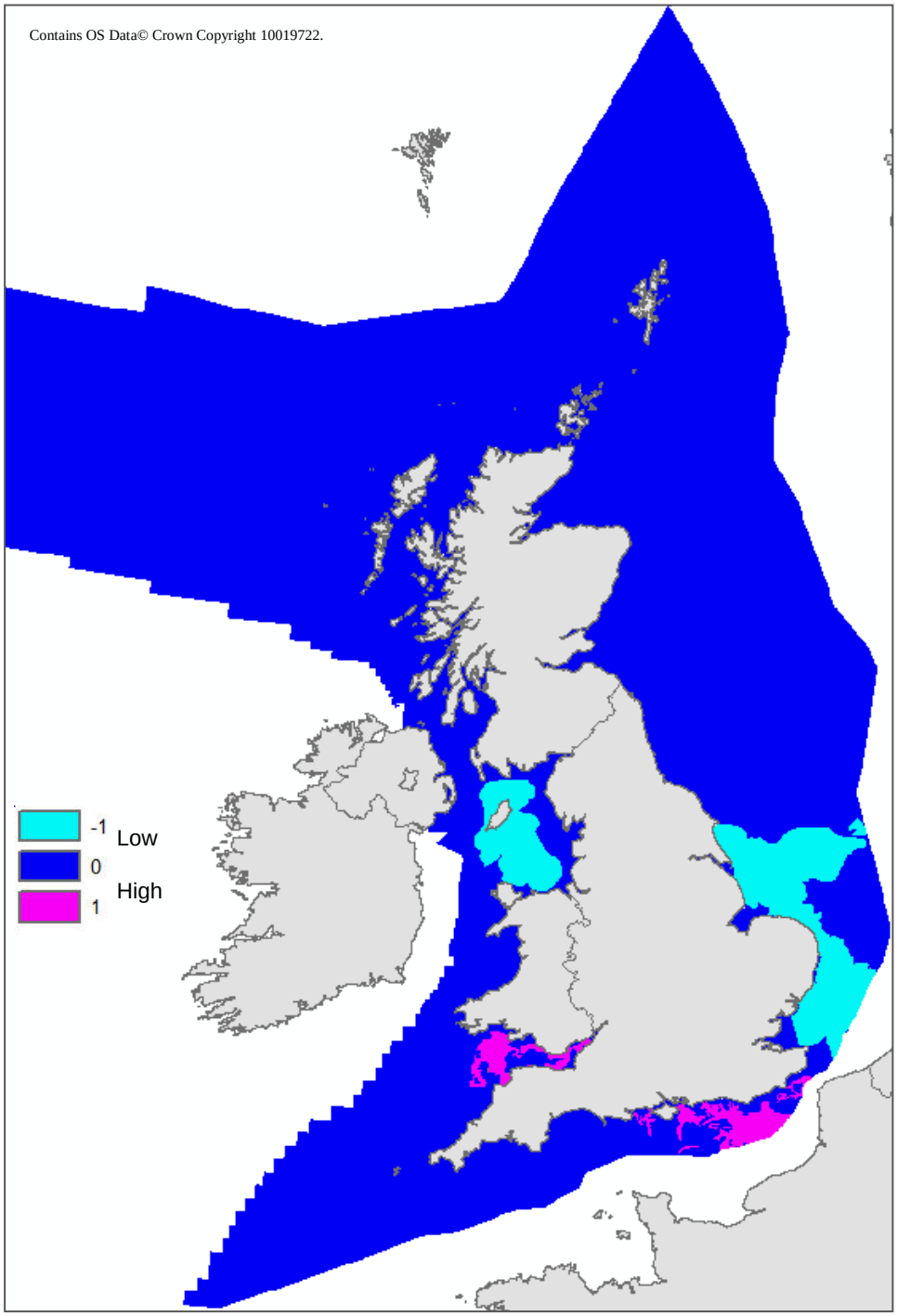

Figure 42: Grid depicting influence of areas containing important resources or area prospective for resources (RESOURCE)

4.2.5 Interpretation Grid Calculation

Arc GIS Raster Calculator was used to add all the grids together (SED_THK + GEOSCI + RESOURCE). The resultant interpretation confidence grid is designed to be combined with the confidence sample grid, exerting an additional positive, neutral or negative score based on qualitative assessment. The actual final score value is irrelevant as it is just a low to higher level of confidence based influencing factors (Figure 43).

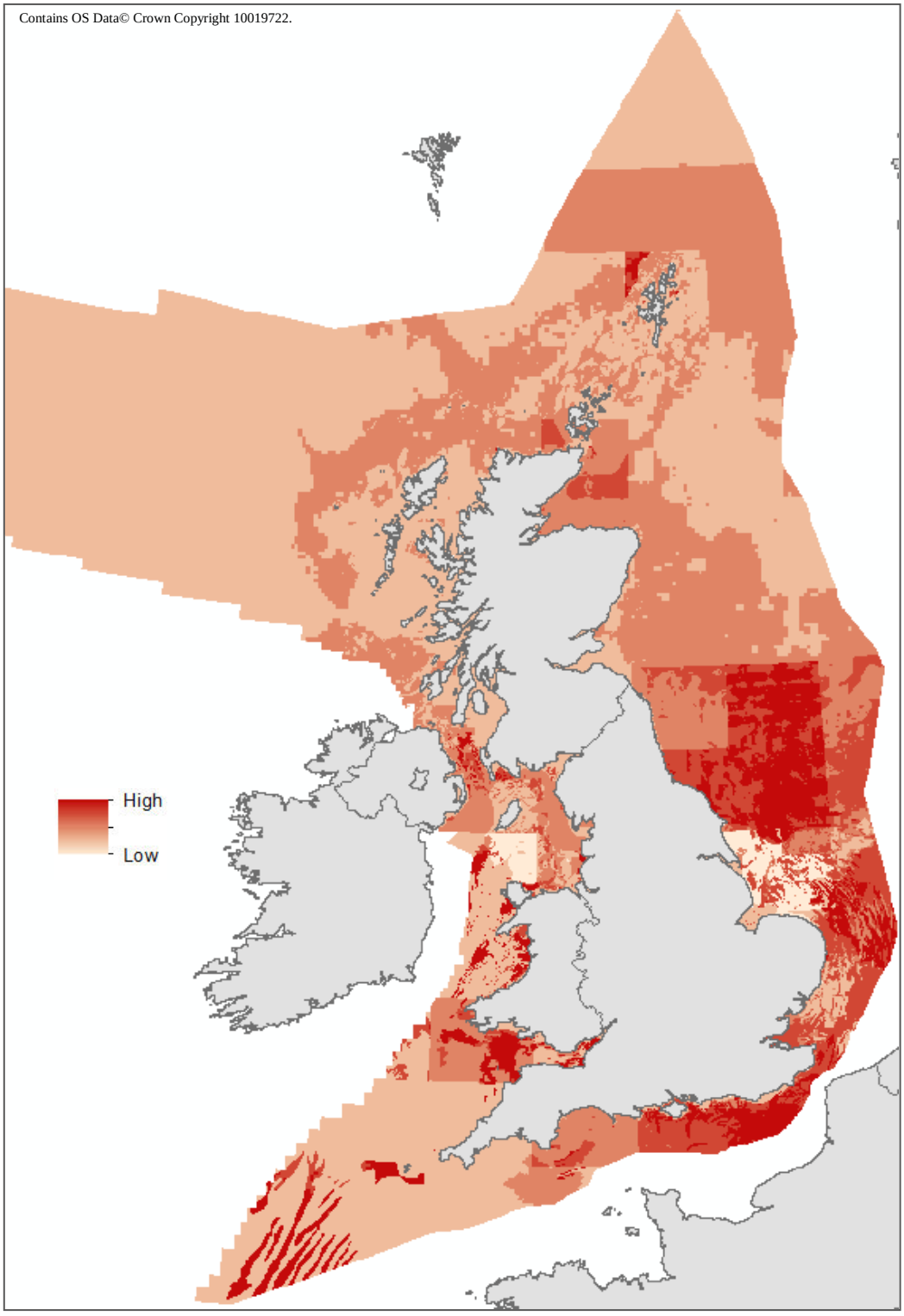

Figure 43: Interpretation confidence grid

4.3 COMBINED SAMPLE AND INTERPRETATION CONFIDENCE GRID

A requirement of this project was to provide a single confidence grid. The sample confidence grid will never have a score higher than 8, the interpreted confidence grid then exerts an additional positive or negative effect, in this case the scores ranged from -2 to 3. To combine the two, the interpretation grid was simply adjusted by adding 2 to get a single positive integer score and then added to the results of the sample grid. This was then divided by 2 to reduce the score back down to single digits again.

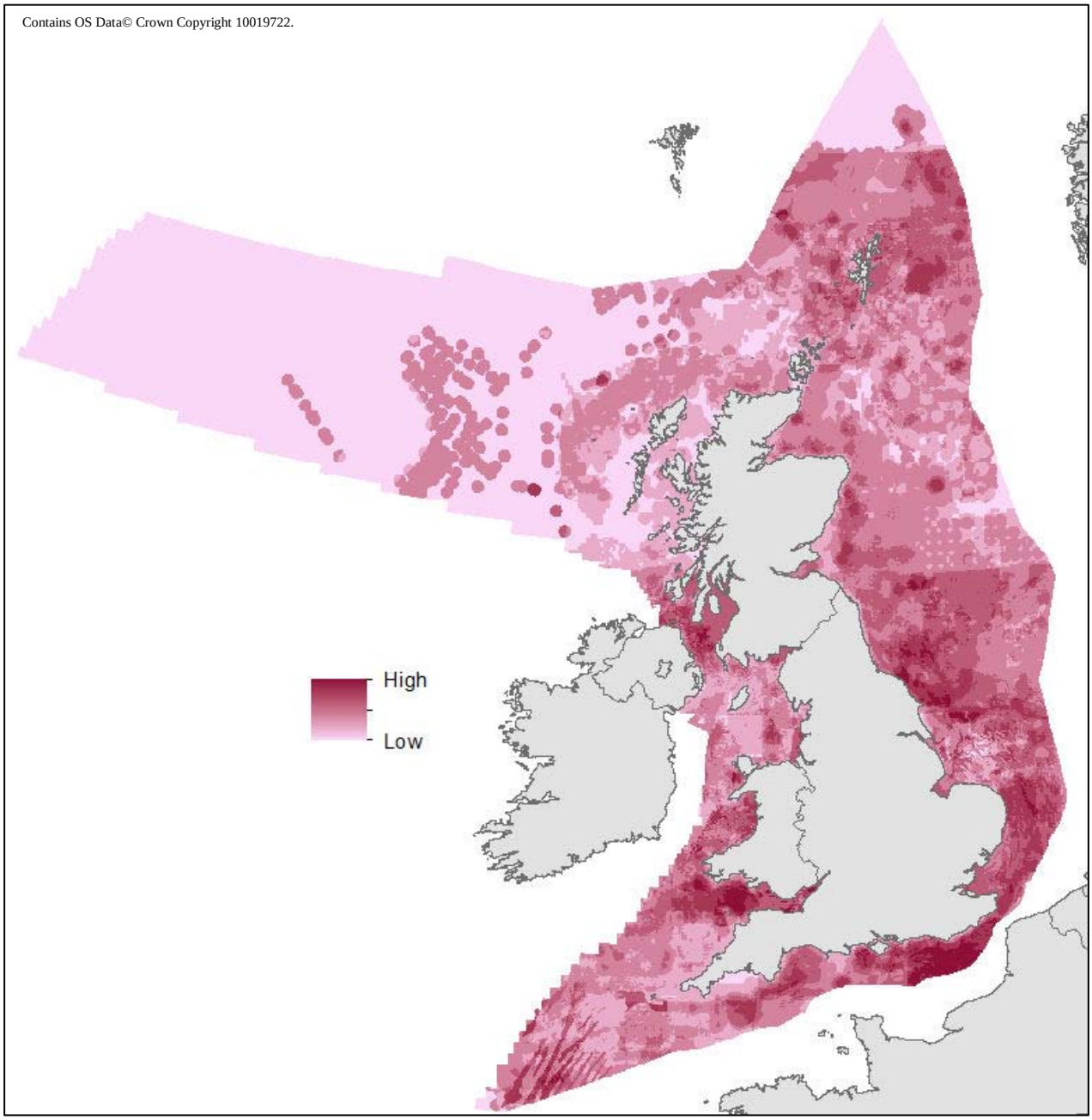

Figure 44: Combined confidence grid

5 Limitations of the dataset

The purpose of the modeling process and resultant data described in this report is to show the broad distribution of mineral resources present for the UKCS suitable for strategic applications. They delineate areas within which potentially workable minerals may occur. These areas may not be of uniform or equal potential and confidence in these areas is variable dependant on the data valuable. These areas of resource also take no account of planning constraints that may limit their working. These maps should not be used to determine the economic potential of individual sites, this 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, but some aggregates dredging does occur in these areas. The presence of these operations generally reflects 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. Therefore marine mineral licences may be located in areas where no resource is shown. It is also possible that local variations in geology that are too subtle to be resolved by this regional-scale survey can contain significant volumes of resource and could prove to be important future resources.

The following limitations also apply:

- The marine aggregate resource data has been developed at 1:250 000 scale (displayed on the maps at a 1:500 000 scale) and must not be used at larger scales. All spatial searches against the data should therefore be conducted using a minimum 250 m buffer.
- The marine aggregate resource map is based on, and limited to, an interpretation of the records in the possession of, or available to, The British Geological Survey at the time the dataset was created.
- The scale of features mapped varies according to the data quality and availability. It should be noted that the level of detail possible for areas with high data density was considerably greater than in less surveyed regions.
- Shoreward polygons are clipped to bay closing lines as defined by the UKHO as of 12/8/2012 or, alternately to, boundaries defined by the limits of data available to this study.
- The marine aggregate resource map was created using the classification scheme described in this report and was designed for use in defining marine aggregates. The dataset should not be used for other purposes and changes to the parameters used in the classification scheme may result in unforeseen outcomes due to limitations of the data.

References

Maps and accompanying reports for the mineral resources of the UKCS:

BIDE, T. P., BALSON, P. S., MANKELOW J.M., SHAW R.A., WALTERS A. S. AND CAMPBELL, E. 2012. The Mineral Resources of the English Channel and Thames Estuary. *British Geological Survey Open Report.* OR/12/096. 28pp.

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