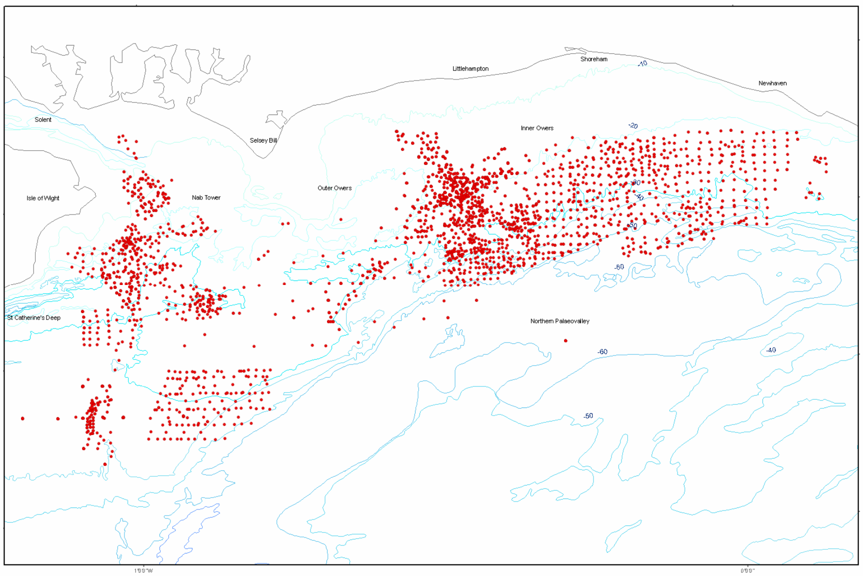
British Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL

The use of marine aggregate data to inform habitat mapping

Marine Geoscience

Open Report OR/08/003



THE CROWN ESTATE

BMAPA

BRITISH GEOLOGICAL SURVEY

MARINE GEOSCIENCE

OPEN REPORT OR/08/003

The use of marine aggregate data to inform habitat mapping

D J R Morgan, E J Bee, J W C James and M P Slater

Keywords

Marine aggregate, marine habitat, English Channel, sand and gravel, marine surveys.

Cover

All sediment sample locations from aggregate industry data.

Bibliographical reference

D J R MORGAN, E J BEE, J W C JAMES & M P SLATER 2008. The use of marine aggregate data to inform habitat mapping. *British Geological Survey Open Report*, OR/08/003. 41 pp.

Keyworth, Nottingham British Geological Survey 2008

BRITISH GEOLOGICAL SURVEY

The full range of Survey publications is available from the BGS Sales Desks at Nottingham, Edinburgh and London; see contact details below or shop online at www.geologyshop.com

The London Information Office also maintains a reference collection of BGS publications including maps for consultation.

The Survey publishes an annual catalogue of its maps and other publications; this catalogue is available from any of the BGS Sales Desks.

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 its basic research projects. It also undertakes programmes of British technical aid in geology in developing countries as arranged by the Department for International Development and other agencies.

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

British Geological Survey offices

Keyworth, Nottingham NG12 5GG

☎ 0115-936 3241 Fax 0115-936 3488
e-mail: sales@bgs.ac.uk
www.bgs.ac.uk
Shop online at: www.geologyshop.com

Murchison House, West Mains Road, Edinburgh EH9 3LA

☎ 0131-667 1000 Fax 0131-668 2683
e-mail: scotsales@bgs.ac.uk

London Information Office at the Natural History Museum (Earth Galleries), Exhibition Road, South Kensington, London SW7 2DE

☎ 020-7589 4090 Fax 020-7584 8270
☎ 020-7942 5344/45 email: bgslondon@bgs.ac.uk

Forde House, Park Five Business Centre, Harrier Way, Sowton, Exeter, Devon EX2 7HU

☎ 01392-445271 Fax 01392-445371

Geological Survey of Northern Ireland, Colby House, Stranmillis Court, Belfast BT9 5BF

☎ 028-9038 8462 Fax 028-9038 8461

Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB

☎ 01491-838800 Fax 01491-692345

Columbus House, Greenmeadow Springs, Tongwynlais, Cardiff, CF15 7NE

☎ 029–2052 1962 Fax 029–2052 1963

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1EU

☎ 01793-411500 Fax 01793-411501
www.nerc.ac.uk

Acknowledgements

The authors would like to thank the following organisations and individuals for their contributions of time and supplying the data used in this study, with a particular acknowledgement to Mark Russell and Mike Cowling for their active support and comments:

Mark Russell, British Marine Aggregate Producers Association

Prof Mike Cowling and Dr Tony Murray, The Crown Estate

Leigh Jones, English Nature

Britannia Aggregates

CEMEX

Hanson Aggregates Marine

United Marine Aggregates

Stuart Gibson, Royal Haskoning

SeaZone Solutions Ltd for provision of digital bathymetric data used in Figure 23

Contents

Acknowledgements ..... **i**

Contents ..... **ii**

1 Introduction **1**

2 Study Area **2**

2.1 Geology 3

3 Data Collation **4**

4 Data Assessment **5**

4.1 Initial Assessment 5

4.2 Maps 5

4.3 Bathymetry 5

4.4 Sea bed morphology and bedforms 6

4.5 Sea bed sediment sample data 8

5 Coding of sample data **9**

5.1 Coordinate Systems 12

6 Published sample data on report CD-ROM **13**

7 Analysis of Sea Bed Sediment Data **13**

7.1 Modified Folk 13
7.2 Particle size and Inverse distance weighting (IDW) analysis 14
7.3 Gridded Folk classification analysis 15

8 Conclusions and recommendations 17

References 18

Figures 19
Figure 1: Location of study area showing mapped limit of aggregate industry data and interpretations 19
Figure 2: Dredging licence areas 20
Figure 3: Aggregate industry bathymetric data: All available contours 21
Figure 4: Example of bathymetric data from an aggregate report 22
Figure 5: Example of bathymetric data overlap 23
Figure 6: Aggregate industry bathymetric data: 5m contours 24
Figure 7: BGS DigBath250 bathymetry 25
Figure 8: Example of side scan sonar interpretation from an aggregate report 26
Figure 9: Example of bedform interpretation from an aggregate report 27
Figure 10: Example of sea bed sediment data from an aggregate report 28
Figure 11: All sediment sample locations from aggregate reports 29
Figure 12: Sediment samples with particle size analysis (PSA) 30
Figure 13: Sediment samples with descriptions 31
Figure 14: Samples with oversize sediment (>37.5mm) 32
Figure 15: Sediment samples – Modified Folk classification 33
Figure 16: Sediment samples with gravel content >50% from PSA analysis 34
Figure 17: Percentage gravel distribution by Inverse Distance Weighting (IDW) – PSA data 35
Figure 18: Percentage sand distribution by Inverse Distance Weighting (IDW) – PSA data 36
Figure 19: Gridded sample station density (500m grid) 37
Figure 20: Gridded distribution of sea bed sediments (all sample locations) 38
Figure 21: Gridded distribution of sea bed sediments overlain on BGS sea bed sediment DigSBS250 map 39
Figure 22: Mud/sand/gravel pie chart for sea bed sediment samples with PSA data 40
Figure 23: Gridded distribution of sea bed sediments overlain on sea bed morphology model 41

CD-ROM .... Inside back cover
Sediment sample data .... BGS_OR_08_003_SedimentSampleData.xls
Report .... BGS_Report_OR_08_003.pdf

1 Introduction

The marine environment is an area where regulation and legislation, both European and national, has been implemented or planned, to control developments on the sea bed. The European Union Habitats Directive is one of the most significant of these. Its principal aim is to provide for the maintenance of biodiversity by conserving rare and threatened species and habitats. Integral to this aim is the designation of a network of Special Areas of Conservation. The Habitats Directive has an impact on aggregate extraction. For application areas, this means that a developer has to satisfactorily demonstrate there are no defined features of potential nature conservation interest, within the terms of the Habitats Directive, in the application area. For existing production licence areas an ‘appropriate assessment’ has to be undertaken by the regulatory authority.

To undertake designations and assessments obviously requires knowledge of the sea bed in terms of its physical character and biological resources, not only within the defined area of exploitation but also on wider scale to place an area of exploitation in its regional context. Habitat mapping has developed in recent years as a response to the requirement to provide integrated mapping incorporating physical and biological parameters and features which can be used to inform the regulatory process.

Physiographic features which include geology, sediment and morphology of the sea bed greatly influence the distribution and range of species and biological communities. It is self-evident there are vast differences between communities which live on hard rocky substrates and those which dwell on and in soft muddy substrates. The advantage of physiographic features such as geology and sediment is they are generally more readily mapped than biological or oceanographic features through the use of geological sampling with grabs and cores and especially by geophysical techniques such as sidescan sonar, seismic reflection and multibeam echo sounder (MBES) systems They are ideally suited to act as principal building blocks of marine habitat classifications. This has been recognised with the inclusion of sediment and substrate at primary levels in habitat classifications.

These forms of geological and geophysical techniques are common practice within the marine aggregate industry when prospecting for potential aggregate resources and in evaluating reserves at licensed production areas. The industry has a considerable amount of survey data collected in areas where prospecting and extraction of marine aggregates has taken place and this data is not generally in the public domain. Since 1990 the industry has surveyed around 16,000 km^2 of sea bed in UK waters, the scale of data coverage offers some potential to develop an awareness for a wider environmental context beyond the boundaries of the existing industry interests. This is potentially useful to industry, regulators and advisors for assessment and management purposes.

The industry has indicated a readiness to allow historical prospecting information to be used for purposes such as habitat mapping, subject to issues of potential commercial sensitivity being maintained. The data was collected purely for the identification of commercial sand and gravel deposits and the sensitivities in the data hinge around criteria such as the identification of resources and conversely, just as significant, the elimination of potential areas of resource, as well as location and operator details.

To allow the utility and value of this data for habitat mapping to be assessed, the British Marine Aggregate Producers Association (BMAPA) and the Crown Estate initiated a pilot study to be undertaken by the British Geological Survey. The pilot study is the subject of this report and has been funded by the Crown Estate, with industry data availability co-ordinated through BMAPA. From an industry perspective, the objective of this study is to explore whether any useful information can be extracted from historical survey data sets collected by the marine aggregate sector to inform a broader regional perspective.

The reports made available to the study contain information on the location of aggregate deposits, sediments, geophysical surveys, sampling data and geological interpretation. Many of the reports include maps of sediment distribution, bathymetry, sidescan interpretations and sea bed morphology. The most valuable and consistent dataset in the reports has been the thousands of log records of sea bed sampling by grabs and vibrocores.

The pilot study is confined to the nature of the sea bed surface and sediment down to a maximum depth of 0.5m, and has only used interpretations and data published in the reports. It has not looked at or re-interpreted original geophysical data such as sidescan sonar and sub-bottom reflection seismic records.

The primary aim of the pilot study is to assess the utility of marine aggregate industry data in providing information to produce maps on three principal themes

1. Bathymetry
2. Sea bed morphology and bedforms (sidescan interpretations)
3. Distribution of sea bed sediments (including sample locations)

The data assessment includes

- Themes and type of data
- Areal extent
- Scale of mapped data
- Density of primary data e.g. samples per km^2, seismic line spacing
- Quality and diversity, e.g. ground truthing of seismic interpretation

The conclusion of the assessment will recommend if any of the principal themes can be developed into a dataset with a common specification to represent all the included industry data.

2 Study area

The pilot study area lies between Beachy Head and St Catherine's Point on the Isle of Wight, stretching some 100 km from east to west, and 40 to 50 km from north to south.

Figure 1 shows the study area and the outer limits of the coverage of aggregate industry maps within the reports made available to the study. It is one of the most significant areas in terms of marine aggregate extraction in the UK with a substantial number of licensed dredging areas (Figure 2). The surveys associated with the exploration, assessment and exploitation of these aggregate dredging areas have been included in the study.

The study area lies on the northern margin of the English Channel. It covers a relatively shallow coastal platform, which is <10 km wide off Beachy Head and becomes progressively wider to the west, reaching a width of 25 km off the Isle of Wight. The surface of the coastal platform declines gently from the coast to a depth of 30 to 40 m (Figure 7). At this depth there is an abrupt break of slope down to a depth of 60 to 70 m. The slope is generally <2 to 3 km wide and occurs on the northern margin of the Northern Palaeovalley, a major open depression within this sector of the English Channel.

There is an extensive complex of filled palaeovalleys and open palaeovalleys within the English Channel (Hamblin and others, 1992; James and others, 2007) and these have a considerable influence on sea bed morphology and the distribution of rock and sediment at the sea bed and the associated distribution of marine habitats. The filled palaeovalleys and their associated sediments are the location of the principal coarse aggregate resource in the study area. The majority of licensed dredging areas are located in a few of these palaeovalley systems. There are five principal palaeovalley systems within the coastal platform. The biggest of these is the Palaeo-Solent, which extends out from beneath the Solent and east of the Isle of Wight. The other significant system in terms of dredged aggregate is the Palaeo-Arun, which lies offshore of Littlehampton (Bellamy, 1995).

2.1 GEOLOGY

2.1.1 Solid

Eocene and Paleocene rocks of Tertiary age, comprising clays, silts and sands with some sandstone, siltstone and mudstone, extend across the middle of the study area, striking WNW-ESE. Cretaceous mudstones and sandstones lie off the southeast coast of the Isle of Wight, and Chalk is present in the south of the study area and the extreme northeast (BGS, 1988 & 1995). The Chalk is the primary source of the flint which comprises a large proportion of the gravel deposits in the area.

The solid geology of the area is varied in terms of its lithology and structure and from a geological perspective these variations could be significant in terms of habitat. Structurally the regional dip of these rocks over most of the area is to the south. This gentle dip is disturbed by flexuring, which form minor east-west trending synclinal and anticlinal folds (James & Brown, 2002). The contrast between hard and soft, bedded rocks within the Tertiary sediments can form small scale scarp features on the sea bed. These indicate that the veneer of sea bed sediment is very thin and the morphology of the sea bed in those areas outside the palaeovalley systems, even on a very minor scale, can be controlled by the underlying solid geology.

The solid geology also controls some of the larger scale morphological features at the sea bed (Figure 23). These depressions can form enclosed environments for the development of megaripples and small sand waves. The Northern Palaeovalley margin is also associated in part with a major anticlinal structural feature. The areas where solid geology is exposed or very close to the sea bed surface are commonly of no interest in terms of aggregates. The industry generally concentrates its survey resources in those areas where there are relatively thick and extensive accumulations of sand and/or gravel such as palaeovalley systems, sand banks and sand wave fields. This has an impact on their overall survey coverage which can be limited in a regional context.

2.1.2 Sea bed sediments

The distribution of sea bed sediments mapped by BGS in the study area (Figure 21) and published at 1:250,000 scale on the Wight and Dungeness-Boulogne sheets (BGS 1989a & b) indicates that the deeper waters within the Northern Palaeovalley are dominated by gravel and sandy gravel sediments. These are principally thin lag gravels lying on rock. These gravelly sediments extend northwards on the coastal platform towards Selsey Bill, into the Solent and eastwards across the platform to the Outer and Inner Owers. In the Solent and Owers areas the gravelly sediments overlie palaeovalley infill and associated sediments as well as forming thin lag gravels on rock

Sandy sediments are confined to the coastal platform, and cover most of the platform east of the Inner Owers and along the coastal margins of the study area; the principal exception being offshore of Selsey Bill. These sands are commonly fashioned by the strong currents in the area into bedforms such as sand waves, megaripples and sand ribbons (Hamblin & Harrison, 1989; Evans & others, 1998)

Sandy sediments also cover much of the slope that forms the margin of the Northern Palaeovalley. These sands are banked against the slope driven by strong currents (James &

Brown, 2002; James and others, 2007). The only significant area of muddy sediment in the study area is within the Solent north-east of the Isle of Wight.

3 Data collation

The initial study plan was based solely on the use of aggregate industry prospecting data which is held in the Crown Estate archive at Royal Haskoning, Haywards Heath. This prospecting data was collected by BGS in February 2005 and comprised some 33 prospecting reports, which included 91 maps, and a large number of logs and interpretations. This data was assessed by BGS and an initial assessment was presented at a steering group meeting in March 2005. It was agreed that the prospecting data was patchy in its quality and extent and did not provide a sufficiently comprehensive coverage of the study area. It was agreed that BMAPA would approach the aggregate companies to seek their co-operation in providing aggregate production data to the study with the emphasis on logs of sediment grabs and cores. Agreement was reached and in late September 2005, BGS collected a further 30 reports with production licence data directly from Cemex, Hanson Aggregates Marine and United Marine Aggregates

The prospecting reports provided 2233 records of sea bed sample data, and the production licence reports gave a further 1437 sampling records. A summary of the contents of the 63 reports was entered, as metadata, into a spreadsheet. A full list of the categories recorded as metadata is shown in Table 1. The assessment and analysis described in this report is based on the combined prospecting and production datasets.

Table 1: Summary of the metadata recorded for reports

Name of Field	Explanation
Project_Report_Number	Unique reference number given to each report
Report_Title	Title of report
Volume	Volume number – if multi-volume report
Type_of_report	e.g. Aggregate Resource Assessment; Survey Report
Place	Place name of survey location
Year	Year of report/survey
Company	Contractor, operator and/or commissioning company
CEC-File No	Crown Estate File No
Authors	Names of report authors (if given)
Comments	Notable features of the report
Maps	Number of maps included in the report
Figures	Number of Figures of significant value to this study
Vibrocore_logs	Vibrocore logs included in report (Y entered if present)
PSA	Particle Size Analysis included in report (Y entered if present)
Lender	Company lending report to BGS
Date Borrowed	Date report received by BGS
Returned	Date report returned to lender

4 Data assessment

4.1 INITIAL ASSESSMENT

An appraisal was carried out for each report on its receipt, assessing the type of data and recording the metadata as specified in Table 1. Since the amount and type of information varied between each report, decisions were made at this stage about the utility and quality of the data, what could be recorded and how it could be of value in terms of producing bathymetry, sea bed morphology and sea bed sediment datasets.

4.2 MAPS

Of the maps provided with the reports, 128 were given a unique identification number and recorded in the database. A total of 109 maps that contained sufficient information about the survey areas, bathymetry, locations of grab and vibrocore sampling, sea bed morphology and sediment distribution were digitally scanned. Most of these were georeferenced and incorporated into the project GIS.

The scanned maps tended to cover wider areas than the actual survey data they contain, therefore, actual survey data coverage, specific to a dataset (e.g. Figure 3 and 11) is a better illustration of data extent.

4.3 BATHYMETRY

Of the 109 scanned maps, 33 had bathymetric data associated with them. For a number of maps bathymetry is subsidiary to the main map topic and is used for geographical reference. All contour lines were digitised and where possible, joined at map sheet boundaries. Figure 3 shows all the digitised bathymetric lines available.

There was a high degree of variance in the quality of the bathymetric data. Some maps included track data with fix, soundings and contours, whilst others showed only contours. The contours used on the various individual maps included 1m, 2m, 5m and 10m intervals. Also some maps were based on Admiralty chart data, not on industry survey data. These would therefore be UK Hydrographic Office (UKHO) copyright and not available for dissemination without UKHO permission.

Where there was a high level of data, such as in licence area 407, the bathymetric interpretation can be detailed with a dense pattern of contours (Figure 3). Where the bathymetric data obtainable was sparser and based on wide survey grids the contour interval has to increase and the contour density is decreased. Figure 3 also clearly demonstrates there are large gaps in coverage across the study area.

Data obtained from different maps often overlapped. However, some individual surveys produced co-ordinated maps with seamless contour joins across their boundaries (Figure 4). In other cases, the contour data were often very different on each map (Figure 5). This can be caused by a number of factors including: -

- Time elapsed between surveys may be long enough for the sea bed to change. This will only be a factor in areas with mobile bedforms or man-made disturbance
- Different survey line density and coverage.
- Different depth datums and tidal corrections.
- Geo-referencing scanned map images based on different co-ordinate systems e.g. National Grid and UTM Lat/Long can produce discrepancies.

An attempt has been made to produce an integrated bathymetry from the aggregate industry bathymetry data. This was based on a 5m contour. This interval was chosen because it enabled the greatest coverage of data to be included and minimised some of the issues with regard to incompatibilities between datasets. This integrated 5m bathymetry is shown in Figure 6. Although the data coverage in the east of the study area is good, it was deemed inappropriate to reduce the contour interval of the digitised dataset to 10m intervals because the data in other parts of the study area would be too sparse.

When compared with the digital 1:250,000 bathymetry produced by BGS called DigBath250 which has contours at 10m intervals (Figure 7) there is certainly more detail in some areas but this is offset by the lack of continuity in coverage across the study area. The availability in 2007 of digital single beam echo sounder data in the area from UKHO/SeaZone Solutions enables sea bed morphology models to be produced (Figure 23), (James and others, 2008) which provide an excellent continuous morphological surface for inclusion in habitat mapping studies.

Conclusions

The bathymetric data included within the study area aggregate industry reports are: -

- Discontinuous and isolated in terms of coverage
- Inconsistent in terms of specification and resolution
- Do not provide an improvement or enhancement when compared with existing digital bathymetric datasets with complete coverage of the study area from BGS (DigBath250) and UKHO/SeaZone Solutions.

The study recommends that bathymetric data from current study area aggregate industry reports should not be re-compiled and made available as an integrated dataset

4.4 SEA BED MORPHOLOGY AND BEDFORMS

The nature of the sea bed in terms of its morphology relates to characteristic physical features which occur on the sea bed. These can be positive features such as scarps or peaks where rock outcrops at the sea bed, drumlins in a drowned glaciated terrain or sand banks in an area of strong tidal currents. They can be negative features such as depressions, channels or deeps. They can form large scale features covering many kilometres such as St Catherine's Deep off the south coast of the Isle of Wight or small scale features such as a rock peak a few metres high.

Bedforms on the sea bed are primarily features which have been fashioned, mainly by currents, although waves can have an influence in shallow water, into distinctive forms. They mainly consist of sediment, predominantly sand, which have produced bedforms such as sand waves, megaripples, sand ribbons, sand streaks and also large-scale features such as sand banks. Gravels and mud can also be fashioned into bedforms, but they are not as common as sand bedforms.

Bedforms are distinctive features and can be important in terms of habitat and aggregate resource. For example, sand banks in <20 m water depth, are a designated feature within the EU Habitats Directive. Sand banks can also be an aggregate resource.

Historically, the principal method for surveying bedforms has been sidescan sonar, although multibeam systems are now beginning to be more common. However, the principal aggregate resource in the study area is gravel associated with palaeovalley systems. The gravels do not commonly have a sea bed expression which can be mapped or delineated by sidescan sonar. The survey methods adopted by the aggregate industry in the study area are focussed on assessing the resource at depth, not at the sea bed surface, through the use of seismic reflection systems and vibrocoring. The value of using sidescan is therefore limited in this area and reflected in the fact that only 15 of the 63 reports had maps with any form of sea bed morphology and bedform data and of these fifteen with sea bed morphology data, only one contains a sidescan interpretation (Figure 8), the majority are typically mapped as in the example seen in Figure 9. Here the sea bed has been delineated into a number of mapped areas with simple descriptions of the nature of the bedforms on the sea bed.

There are a number of issues with the sea bed morphology data: -

- They have the least coverage of the three themes under assessment
- No common classification has been adopted across the dataset
- Simple bedform and morphological descriptions, some of which are tentative
- Minimal or non-existent bedform information on features such as crest line height and orientation.
- Some maps have no boundaries delineating interpreted areas, some have open polygons.
- Some maps have contradictory interpretations.
- Source of interpretation not always given in terms of survey method, survey density and coverage.

Conclusions

The sea bed morphology and bedform data included within the study area aggregate industry reports are: -

- Discontinuous and isolated in terms of coverage
- Inconsistent in terms of classification, attribution and resolution

Producing a common specification would be difficult and the resulting interpretation would be very simple and limited in its coverage and therefore of little utility in terms of habitat mapping and nature conservation. Going back to re-interpreting the original sidescan data would resolve some of these issues but this is likely to be time consuming, not cost effective and continue to be limited in its coverage.

It is not unexpected that the sea bed morphology and bedform data appears so unpromising and it is not a reflection of the quality of the original data or interpretations. The variety of interpretations is simply a reflection of the required purpose and the lack of a common standard in terms of mapping bedforms from sidescan records within the geological community, unlike, for example, in sediment interpretations where there are recognised international standard particle size classifications such as Folk or Wentworth. Although the study recommends that sea bed morphology and bedform data from current study area aggregate industry reports should not be re-compiled and made available as an integrated dataset, there may be some merit in using individual industry bedform interpretations in the future to ground truth regional sea bed morphology models such as depicted in Figure 23.

4.5 SEA BED SEDIMENT SAMPLE DATA

The nature of an aggregate resource in terms of its lithology and grain size is obviously critical in meeting standards with regard to aggregate specifications. There is no substitute for physical evidence in undertaking a resource assessment and the aggregate industry invest heavily in sampling with grabs and coring (Figure 10) and there is a wide coverage of mapped sea bed sediment data in the reports. In total there were over 3600 sediment sample stations in the industry reports. The locations of the stations included in the study are plotted in Figure 11. They have an excellent coverage across the coastal platform from the Owers to Newhaven and also good coverage east and south-east of the Isle of Wight. Sampling density is generally better than one per 2 km square and can reach densities of ten per 0.5 km square (Figure 19).

Commonly there are little or no samples in water depths <20 m. The coastal platform between the Owers and the area east of the Isle of Wight is sparsely covered by sample stations but is relatively well distributed and comparable, if not better, than sample distributions used to produce BGS 1:250,000 sea bed sediment maps.

Sediment sampling was carried out by vibrocore or grab, with both techniques being used in many surveys. In the case of vibrocores, the sediments typically had a graphic log along with a lithological description. The results of Particle Size Analysis (PSA) were also given for selected samples (Figure 12). Grab samples were usually given only a description, but occasionally PSA was also carried out on them.

Conclusions

The sea bed sediment sample data included within the study area aggregate industry reports are: -

- Relatively abundant and well distributed
- Generally produced at a quality which allows extraction to a standard sedimentological specification and description
- Supported at many stations by particle size analysis which produces a standard sedimentological specification and description
- Convertible into standard geological classifications which can be assessed and mapped

The study recommended to the steering group that the sample station dataset provided the best option for producing maps and data which could be utilised in habitat mapping, and specifications and methodologies should be produced for comment and analysis as the next stage of the study. The sections that follow describe the analysis of the industry sea bed sediment data and the methods which were assessed and adopted to produce a number of specifications and outputs to illustrate its application to habitat mapping.

5 Coding of sample data

Information about the vibrocore and grab samples was recorded in a table within the project database. The attributes recorded are listed in Table 2.

Table 2: List of attributes recorded from the sediment sample logs

Column Heading	Explanation
BGS_Report_Number	Unique reference number given to each report
BGS_Map_Number	Unique reference number given to each map within reports
Contractor_Number	Contractor's identification no. for sample station
Unique_Location_Ref	Reference number unique to sample location
ME_OSGB	British National Grid Easting
mN_OSGB	British National Grid Northing
Sample_Type	Sampling technique – grab or vibrocore (occasional bag sample)
Date	Date of sampling or analysis
Terminal_depth_M	Terminal depth of sample – nominally 0.3m for grab samples
Depth_top	Top of sample depth range (relative to sea bed)
Depth_base_M	Base of sample depth range (relative to sea bed)
Mud_PER	Percentage of mud (< 0.0625m)
sand_5mm	Percentage of sand based on 5mm sand/gravel threshold
Gravel_5mm	Percentage of gravel based on 5mm sand/gravel threshold
SandPER	Percentage of sand based on 2mm sand/gravel threshold
GravelPER	Percentage of gravel based on 2mm sand/gravel threshold
Oversize_present	Oversize (> 37.5mm) recorded in analysis
Oversize_percent	Percentage of oversize (> 37.5mm) in analysis
Folk	Folk classification of sediment type
Bedrock	Lithology of bedrock encountered during sampling
Depth_Bedrock	Depth of bedrock below sea bed, where encountered
Additional_comment	Additional comment
PSA_Y_N	Partical size analysis carried out on sample (Y or N)
Intepretation_technique	Either PSA or logger's description
Coord_system	Geographical coordinate system used in the survey
Degrees_N	Degrees north (where Degrees Minutes Seconds - DMS used)
Minutes_N	Minutes north (where DMS used)
Seconds_N	Seconds north (where DMS used)
Degrees_W	Degrees west (where DMS used)
Minutes_W	Minutes west (where DMS used)

Seconds_W	Seconds west (where DMS used)
Decimal_degrees_N	Latitude in decimal degrees
Decimal_degrees_W	Longitude in decimal degrees
Comments	Notable features relating to the sample
J_Decca_coord	J - Decca coordinate
H_Decca_coord	H – Decca coordinate
A_Decca_coord	A – Decca coordinate
UTM30_E	Easting in UTM zone 30 in metres
UTM30_N	Northing in UTM zone 30 in metres

In order to unify the information from sample descriptions and PSA from 63 different reports to a common standard, it was concluded that each sediment sample should be coded using the Folk classification (Folk, 1954). Each sample was classified into one of the 15 categories (Table 3 & 4) so that the data could be manipulated and displayed systematically in the project GIS.

Table 3: The Folk Classification System.

Code	Sediment category
M	Mud
sM	Sandy mud
(g)M	Slightly gravelly mud
(g)sM	Slightly gravelly sand mud
gM	Gravelly mud
S	Sand
mS	Muddy sand
(g)S	Slightly gravelly sand
(g)mS	Slightly gravelly muddy sand
gmS	Gravelly muddy sand
gS	Gravelly sand
G	Gravel
mG	Muddy gravel
msG	Muddy sandy gravel
sG	Sandy gravel

In total, over 3600 sample data records were entered, of which 3137 were used in the study (Figure 11) and 955 of these included Particle Size Analysis (PSA) data (Figure 12).

When coding the descriptions, wherever possible the assumption was made that the logger was describing the sediment in a systematic fashion which could be translated into a Folk classification. For example, a sample described as “silty fine sandy GRAVEL” would be coded as “msG”. However, much more complex descriptions were often encountered, such as: “Yellow brown fine to medium shelly SAND. Silt, clay and soft sandstone pebbles at depth”. In such cases, some degree of judgement had to be used to decide how this characterised the sediment at the sea bed. Greater weight was given to the sediment near the surface, so the above example would be coded as “gmS”.

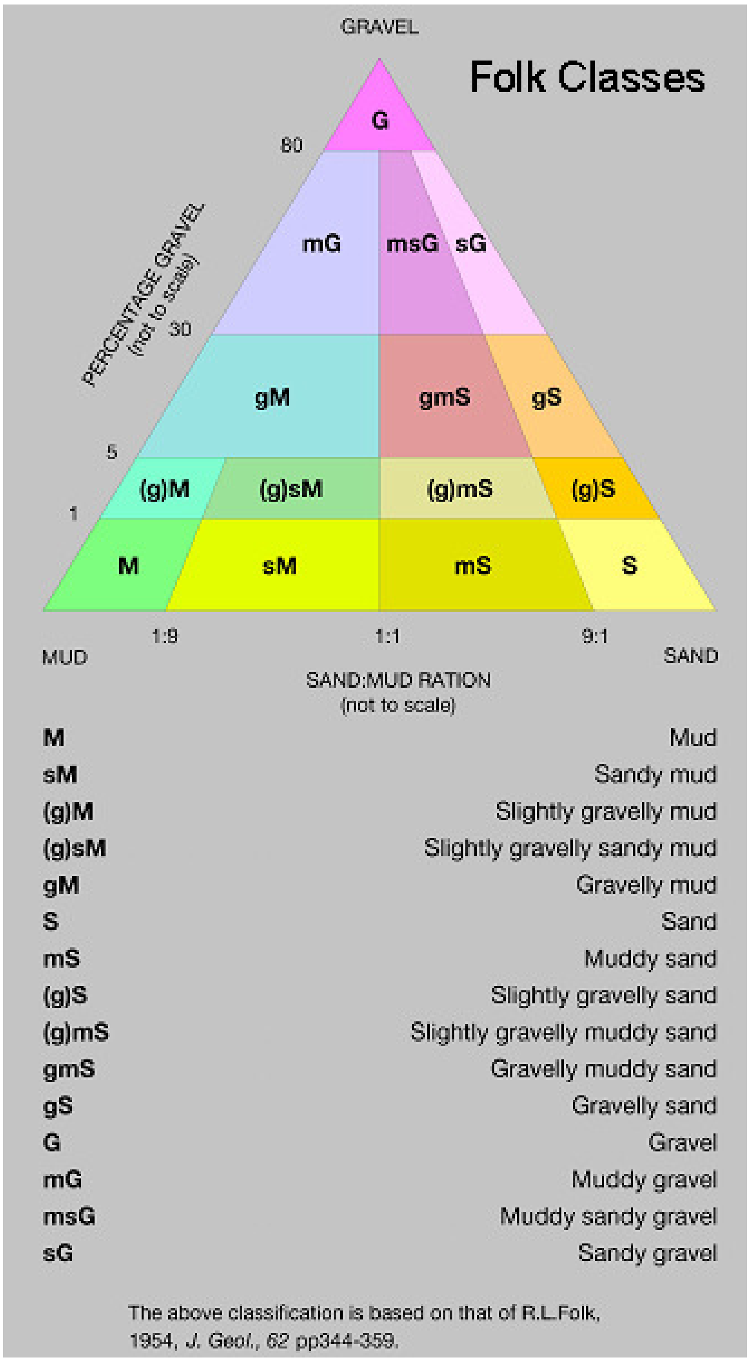


Table 4: The Folk Classification System & Triangle.

The PSA data were usually presented as percentages of sediment passing through each size threshold, and as graphic grading curves. The percentage figures were used by preference, but where these were not available, percentage figures were read off the grading curves.

For samples with PSA (Figure 12), the Folk coding could be applied more rigorously, using the ratios and percentages shown in Table 4. Initially, the size thresholds used were 0.0625 mm to 0.075 mm for mud/sand - depending on the specification of the survey, and 2mm for sand/gravel, as per Wentworth (1922); the standard sand/gravel boundary used by the academic community. The steering group agreed that the 5 mm threshold for sand/gravel, as per BS 882 (1992) would also be included in the database. The data interpreted before March 2005 was re-analysed using the 5 mm threshold.

Where available, the percentage of oversize (>37.5 mm) sediment present was recorded and entered in the database. 483 samples included oversize material (Figure 14)

For grab samples, a nominal depth of 0.3 m was assumed, and the descriptions and PSA were usually taken as representing the surface and shallow sub-surface deposits.

Descriptions of the top 0.5 m of the vibrocore samples were dealt with in the way described above, paying particular attention to the top 0.3 m, with a bias towards the sediments in the uppermost 5-10 cm.

The majority of samples that have Folk classifications derived from PSA, also have Folk classifications derived from the loggers' descriptions. Due to the subjectivity of the loggers' descriptions, and the fact that the PSA and description sometimes related to different depth intervals, the two Folk classifications often differ. More credence should be given to the PSA data, as they should be more consistent.

Bedrock was sometimes encountered at, or near the sea bed surface. The presence of bedrock, its depth and lithology were recorded in the appropriate fields in the database. Where clays described as "stiff", "very stiff" or "hard" were encountered, they were presumed to be bedrock. However, there is some uncertainty about whether such sediments are bedrock or superficial cover, so they have been recorded as "?bedrock" in the comments field. This is especially true of areas that overlie mapped chalk.

Where the depth to bedrock was not known e.g. sample described as "veneer sandy gravel over sandstone", a nominal depth of 0.1 m was recorded. Where there was no superficial cover (i.e. bedrock at sea bed), zero has been entered in the Depth_Bedrock field, and R entered as the Folk classification.

The penetration depth of vibrocore was taken as the Terminal Depth. Where penetration depth was not recorded, the core length was used.

5.1 COORDINATE SYSTEMS

The sample station geographical positions were recorded in various reports using four coordinate systems, although the great majority of records were located with British National Grid (BNG).

The systems used and the number of related records were:-

- British National Grid (BNG)- 2589 records.
- Degrees latitude and longitude - 527 records.
- UTM zone 30N coordinates - 25 records
- Decca Navigator System - 525 records

Since most of the data, including the report maps, were in British National Grid, it was agreed by the steering group to use BNG for the project. The samples located by Decca coordinates have not been included in the project GIS due to doubts over both the precision of the locations, and a reliable way of converting them into BNG.

6 Published sample data on report CD-ROM

A CD-ROM is provided with this report (wallet inside back cover) and includes edited data extracted from the sediment sample table in the project database. The data is provided in a Microsoft Excel spreadsheet - BGS_OR_08_003_SedimentSampleData.xls

For each sample station the attributes recorded in the spreadsheet are: -

- Unique sample reference number
- Date of sampling
- Sample geographical location
- Folk classification.

The attribute column headings are as given in Table 2. The data in the spreadsheet are tabulated within four worksheets; one for each of the four different coordinate systems used in the original surveys i.e. British National Grid, Decimal degrees, UTM and Decca.

The data originally recorded in the project database often had more than one sediment analysis per sample station. This was because the results of both visual inspection and PSA were recorded, and also data was recorded for different sediment layers within the top 0.5m or so. In this edited version, such duplication is removed and the Folk classification produced represents the sediment lying at the surface of the sea bed.

The sample station data provided in the spreadsheet on the report CD-ROM is the copyright of the British Marine Aggregate Producers Association (BMAPA). It is made available for scientific research provided acknowledgement is given of the source of the data. Any commercial exploitation of the sample station data will require the approval of BMAPA.

The CD-ROM also includes a pdf copy of this report.

7 Analysis of sea bed sediment data

The analysis of the industry sea bed sediment data and the specifications and outputs described in this section are based on two primary datasets

1. Folk classification of individual sample stations
2. Particle size analysis (PSA) of individual sample stations

Figure 11 shows all sea bed sediment sample data gathered that could be utilised for the analysis within the GIS. These total 3137 sample stations. The 955 samples that contain PSA are also mapped on Figure 12. Figure 13 shows the location of sample sites for which sample descriptions were given. PSA was also carried out on many of these samples with descriptions; hence the duplication of sample sites when compared with the PSA data in Figure 12.

7.1 MODIFIED FOLK

During the initial stage of the study a map was produced of sea bed sediment distribution based on the fifteen Folk classes (Table 4). Paradoxically, because of the relatively high density of sample stations in the study area the mapped sediment distribution was very complex in terms of polygons and boundaries. The map was presented to the steering group and an alternative was proposed by BGS to adopt a modified Folk classification for the study based on seven rather than fifteen classes. This was agreed by the steering group.

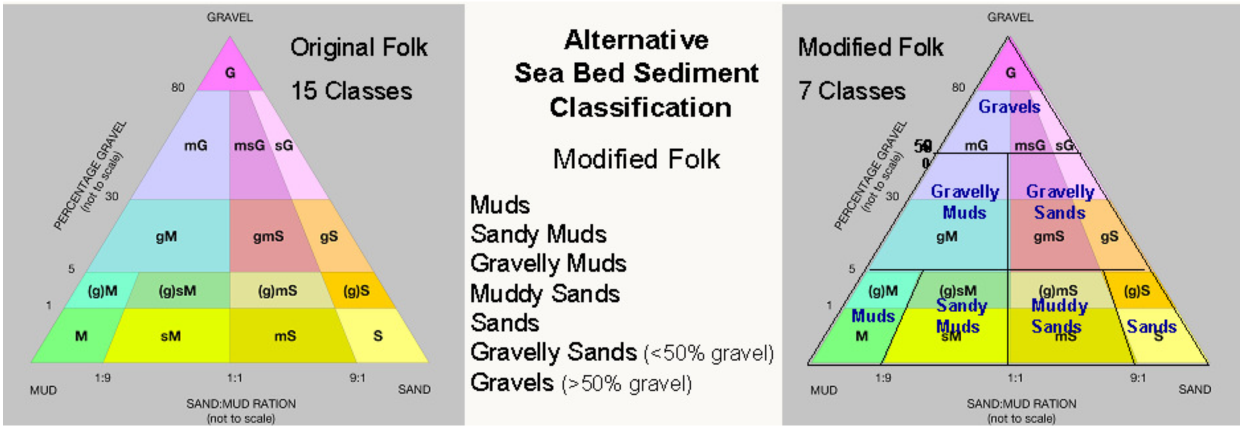


Table 5: The original Folk classification system and its modified version.

The Modified Folk classification is shown in Table 5. The principal modifications from the original classification are the elimination of the slightly gravelly category, and the gravel category being widened to include all sediment with >50% gravel with the loss of the sandy gravel category.

The distribution of the sediment samples, based on the modified classification is shown in Figure 15. Gravelly sediments are dominant east of the Isle of Wight and across to the Owers area. To the east of the Owers, sands become more common especially on the slope margin of the Northern Palaeovalley. Although the classification has been simplified there is still a relatively complex pattern of sediment distribution within the gross picture that the use of coloured dots does not address. Polygons could be drawn by hand around the sample points and digitised but this would be time consuming and not provide a wholly satisfactory solution. A more automated mapping approach within a GIS might provide a better solution and sections 7.2 and 7.3 describe some approaches that have been tried.

7.2 PARTICLE SIZE AND INVERSE DISTANCE WEIGHTING (IDW) ANALYSIS

Particle size analysis data allows a statistical approach to the analysis and representation of sediment. 955 samples included PSA data and although this only represents about 30% of the total sample station data available to the study, it does have a reasonably extensive coverage across the study area (Figure 12).

A sediment characteristic that can be drawn from the PSA data is oversize material. This is sediment which is >37.5 mm in diameter in aggregate grain size definition. This is not a large diameter as a boundary for defining relatively coarse sediment, for example, cobbles are defined in the geological Wentworth scale as >64 mm. It should also be borne in mind when using oversize evidence that the maximum diameter of sampled material is limited to the footprint of the grab or corer used to collect the sample. If the open jaws of a grab cover 30 x 30 cm it would not be able to recover gravel with diameters >30 cm. However, oversize material is an indication of relatively coarse sediment at the sea bed within the gravel fraction. It may be significant in terms of habitat, possibly indicating a relatively stable sea floor since gravel of these dimensions could be immobile. The distribution of oversize sediment (Figure 14) is as relatively widespread across the study area as the occurrence of gravel, and correlates with those areas where gravel is >50% within a sample (Figure 16). There do not appear to be any areas where oversize material is conspicuous by its absence compared to gravel,

PSA data has also been used to indicate the proportions of gravel, sand and mud by producing a pie chart for each sample station (Figure 22). This illustrates very well the lack of mud in the samples and the dominance of sand and gravel. Not surprising as muddy sediment would not be a target for aggregate surveys, indeed would normally be actively avoided during aggregate sampling investigations.

The results from the methods adopted above have all been illustrated in the their respective figures as sample point sediment data. This is a perfectly reasonable method of indicating the nature of sediment distribution especially in areas of dense sampling, as is the case in some parts of the study area. In terms of employing this sample station data to produce sea bed sediment distribution maps we investigated the use of automated methods utilising the GIS, using PSA and non-PSA data.

As its name implies, the Inverse Distance Weighting (IDW) technique assumes the weight of a value decreases as the distance increases from the prediction location. Deterministic interpolation techniques apply established mathematical formulae to the sample points. In the case of IDW, the formula is: multiply the values of the 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.

Drawing contours based on the Folk description alone would be purely subjective, and it is not easy to produce an interpolation map based on descriptive values. However, with PSA data, interpolation maps, using the IDW technique were generated for percentage gravel (Figure 17) and percentage sand (Figure 18).

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 (such as IDW) use a small area around a 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 data samples are sparsely located.

Although the interpolation in Figure 17 for gravel is influenced in some parts by the bull's eye effect of sparse data, it does highlight those areas where gravel is most abundant and confirms the trends evident from the whole sample station dataset. The interpolation for sand (Figure 18) is obviously the inverse of gravel. Both figures show up variations in the proportions of sand and gravel which may be significant in terms of habitat.

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 prediction map is weakest where there are outliers or no data. It should therefore be used with caution in these areas.

7.3 GRIDDED FOLK CLASSIFICATION ANALYSIS

Although the IDW technique is important in indicating trends and patterns based on quantitative PSA data to produce mapped units, it does not have the number or density of coverage in comparison with the qualitative Folk classification data which forms the primary dataset available. We therefore considered techniques utilising the GIS to produce mapped polygons of sea bed sediment distribution based on the modified Folk classification data.

A methodology using a grid and a point in grid (point in polygon) analysis was conducted on all sea bed sediment sample data in order to increase the coverage of the data set. A grid of 500 m by 500 m squares was built to cover the study area and the extent of all sea bed sediment sample data.

The initial part of the analysis used an algorithm to count the number of samples that fell within each 500 m grid square. Figure 19 shows the density distribution of sea bed sediment samples within each grid square. It is clear that the intensity of samples is greatest within licence areas in the Owers with a number of grid squares containing over ten stations. The density can be used as a quality control/ confidence analysis of the dataset.

The next stage within this methodology was to calculate the Folk classification value for each grid square. Those squares with only a single sample station, and these were the majority of squares in the study area, were given the Folk classification of that single station. For the remaining squares the calculation is a little more complicated. Those squares containing **three** or more sample stations and which had a majority with a specific Folk classification were designated with the majority value that occurred most frequently. For example, where 5 samples fell within a square and two were classified as Muddy Sand and three as Sand, then the square was classified as being Sand. This was because Sand occurred most frequently within the grid square.

For those squares with **two** or more sample stations with an equal number of modified Folk classifications a simple rules system was devised based on an interpretation of the proportions of gravel, sand and mud to produce a single classification for the relevant square. The resulting gridded modified Folk classification map is shown in Figure 20.

One of the principal aims of making aggregate industry data available is to place the sea bed areas and sediments utilised in aggregate extraction in a regional context. The principal regional scale sea bed sediment map of UK waters is the BGS 1:250,000 series which in a digital form is called DigSBS250. Both English Nature and JNCC have used this map in assessing the sea bed for habitat designation. We thought it would be pertinent to compare the gridded Folk classification map (Figure 20) with the BGS DigSBS250 map. This would be a form of quality assurance and confirmation for both datasets, and at a regional scale they should be complimentary.

Figure 21 includes the DigSBS250 map for the study area overlain by the gridded Folk map. The colours of the gridded sediments are the same as colours for the DigSBS250 sediments. Therefore if the grid and DigSBS250 sediments are the same they will merge with only the black outline of the grid visible. It should be noted because the grid is based on a modified Folk it does not include sandy gravel (pale pink) or slightly gravelly sand (dark orange). The sandy gravel equivalent on the grid is likely to be gravel (magenta) and the slightly gravelly sand is sand (yellow).

The comparison between the two mapped datasets does indeed indicate a great deal of compatibility on a regional scale. The main areas of coarse sediment east and south east of the Isle of Wight and across to the Owers is confirmed on both maps, with the grid indicating that gravels continue east along the coastal platform. Similarly both maps confirm the sands which occur along the slope margin of the Northern Palaeovalley with the grid indicating they extend further west than shown on DigSBS250. On a local level the numerical advantage of the gridded dataset does indicate the variety of sediments that can occur, for example, individual sandy grids in gravelly sediments possibly indicative of thin sandy bedforms. It also has notable occurrences of rock outcrops and occasional muddy sediment.

The density and extent of the sample station data warranted a 500 m square grid. This appears to be a good compromise between detail, confidentiality and areal coverage. Other grid sizes could be utilised if necessary.

One of the premises of making this type of data available is the value it can add to any surveys, data or interpretations conducted in the future. An excellent example of this premise is the recent availability of digital single beam echo sounder data from UKHO/SeaZone Solutions and the sea bed morphology models that can be produced from this data (James and others, 2008). Figure 23 is a sea bed morphology model covering this project area which has been produced from digital single beam echo sounder data made available to the study by Sea Zone Solutions for illustrative purposes.

It is not within the remit of this project to undertake any interpretations but the quality of this model would allow the sediment sample data to provide excellent ground truthing of the major morphological features apparent on the model such as the palaeo-Solent and palaeo-Arun valleys, and the sand wave fields and banks on the margin of the Northern Palaeovalley.

8 Conclusions and recommendations

The results of the pilot study in the area between St Catherine's Point and Beachy Head indicates that the marine aggregate industry has a considerable amount of survey data within its prospecting and production reports, from which can be extracted geological information to produce derived data for use within studies such as habitat mapping. This derived data is relatively extensive on a regional scale and provides a wider environmental context beyond the boundaries of existing industry interests. It has the potential to be of value to industry, regulators and advisors for assessment and management purposes.

There are commercial sensitivities in the use of any data within marine aggregate industry reports and these must be borne in mind when derived datasets are produced.

The study looked at three principal themes within the aggregate reports

- Bathymetry
- Sea bed morphology and bedforms (sidescan interpretations)
- Distribution of sea bed sediments including sample locations

It concluded that the bathymetry available in the reports did not provide any improvement or enhancement to existing digital bathymetric data sets particularly with the recent availability of regional sea bed morphology models based on extensive single beam echo sounder data.

The study recommends that sea bed morphology and bedform data from current study area aggregate industry reports should not be re-compiled and made available as an integrated dataset, although there may be some merit in using individual industry bedform interpretations in the future to ground truth regional sea bed morphology models such as depicted in Figure 23.

It is not unexpected that the sea bed morphology and bedform data appears so unpromising and it is not a reflection of the quality of the original data or interpretations. The variety of interpretations found within the aggregate industry reports is simply a reflection of the required purpose and the lack of a common standard in terms of mapping bedforms from sidescan records within the geological community. However, if the study is extended to other areas any sea bed morphology and bedforms should be assessed in case they have better coverage and consistency in terms of interpretation

There is no substitute for physical evidence in undertaking a marine aggregate resource assessment and the aggregate industry invests heavily in sampling with grabs and coring. In total there were over 3600 sediment sample stations in the industry reports. The sea bed sediment sample data are the most valuable and consistent dataset. They are relatively abundant and well distributed with particle size analysis and descriptions that are convertible into standard geological classifications such as Folk (Table 5).

The study indicates that the sample station dataset provides the best option for producing maps and derived data. For example, the gridded Folk classification analysis (section 7.3) produced a dataset that had a great deal of compatibility on a regional scale with the BGS DigSBS250 sediment map. This type of sediment data can add value to any surveys, data or interpretations conducted in the future. Bedforms and features within sea bed morphology models, which have recently become available (Figure 23), could be ground truthed with industry sediment sample data.

This is the first time a study has been conducted to assess the utility of aggregate industry prospecting data and it has confirmed that the industry has a wealth of survey data that can contribute to regional scale sediment and habitat mapping. The issues with regard to confidentiality and coverage can be addressed with the map options produced in this report and the sediment sample data made available in the accompanying CD-ROM.

References

Bellamy, A. G. 1995 Extension of the British Landmass: evidence from shelf sediment bodies in the English Channel. 47-62 in *Island Britain: a Quaternary perspective* Preece, R.C. (editor) (London: Geological Society Special Publication No. 96)

BGS 1988. Dungeness-Boulogne (50ºN- 0º) Solid Geology. 1:250,000 Map Series, British Geological Survey, HMSO.

BGS 1989a. Wight (50ºN- 02ºW) Sea bed sediments and Quaternary Geology. 1:250,000 Map Series, British Geological Survey, HMSO.

BGS 1989b. Dungeness-Boulogne (50ºN- 0º) Sea bed sediments and Quaternary Geology. 1:250,000 Map Series, British Geological Survey, HMSO.

BGS 1995. Wight (50ºN- 02ºW) Solid Geology (Second Edition). 1:250,000 Map Series, British Geological Survey, HMSO.

Evans, C.D.R., Crosby, A., Wingfield R.T.R., James, J.W.C., Slater, M.P. and Newsham, R. 1998. Inshore Sea bed Characterisation of selected sectors of the English Coast. *British Geological Survey Technical Report* WB/98/45

Folk, R.L. 1954. The distinction between grain size and mineral composition in sedimentary rock nomenclature. *Journal of Geology* Vol. 62, no.4 345-351

Hamblin, R.J.O., and Harrison, D.J. 1989, The marine sand and gravel resources off the Isle of Wight and Beachy Head: *British Geological Survey Technical Report* WB/89/41.

Hamblin, R.J.O., Crosby, A., Balson, P.S., Jones, S.M., Chadwick, R.A., Penn, I.E., and Arthur, M.J. 1992. The geology of the English Channel. *United Kingdom Offshore Regional Report*: (London, HMSO for the British Geological Survey) 106 pp.

James, J.W.C. & Brown, C.J. 2002. Marine habitats off Shoreham, eastern English Channel: A geological perspective. *British Geological Survey Commissioned Report* CR/01/60

James, J.W.C., Coggan, R.A., Blyth-Skyrme, V.J., Morando, A., Birchenough, S.N.R., Bee, E., Limpenny, D.L., Verling, E., Vanstaen, K., Pearce, B., Johnston, C.M., Rocks, K.F., Philpott, S.L. AND Rees, H.L. 2007. The Eastern English Channel Marine Habitat Map. *Cefas Science Series Technical Report* 139. Cefas, Lowestoft. 191 pp.

James, J.W.C., Coggan, R.A., Rocks, K.F and Iwanoczko, A.P. 2008. Application of sea bed morphology modelling from single beam echo sounder data for habitat mapping in the Eastern English Channel. *British Geological Survey Open Report* OR/08/016

Wentworth, CK, 1922. A scale of grade and class terms for clastic sediments, *Journal of Geology* Vol.30, 377-392

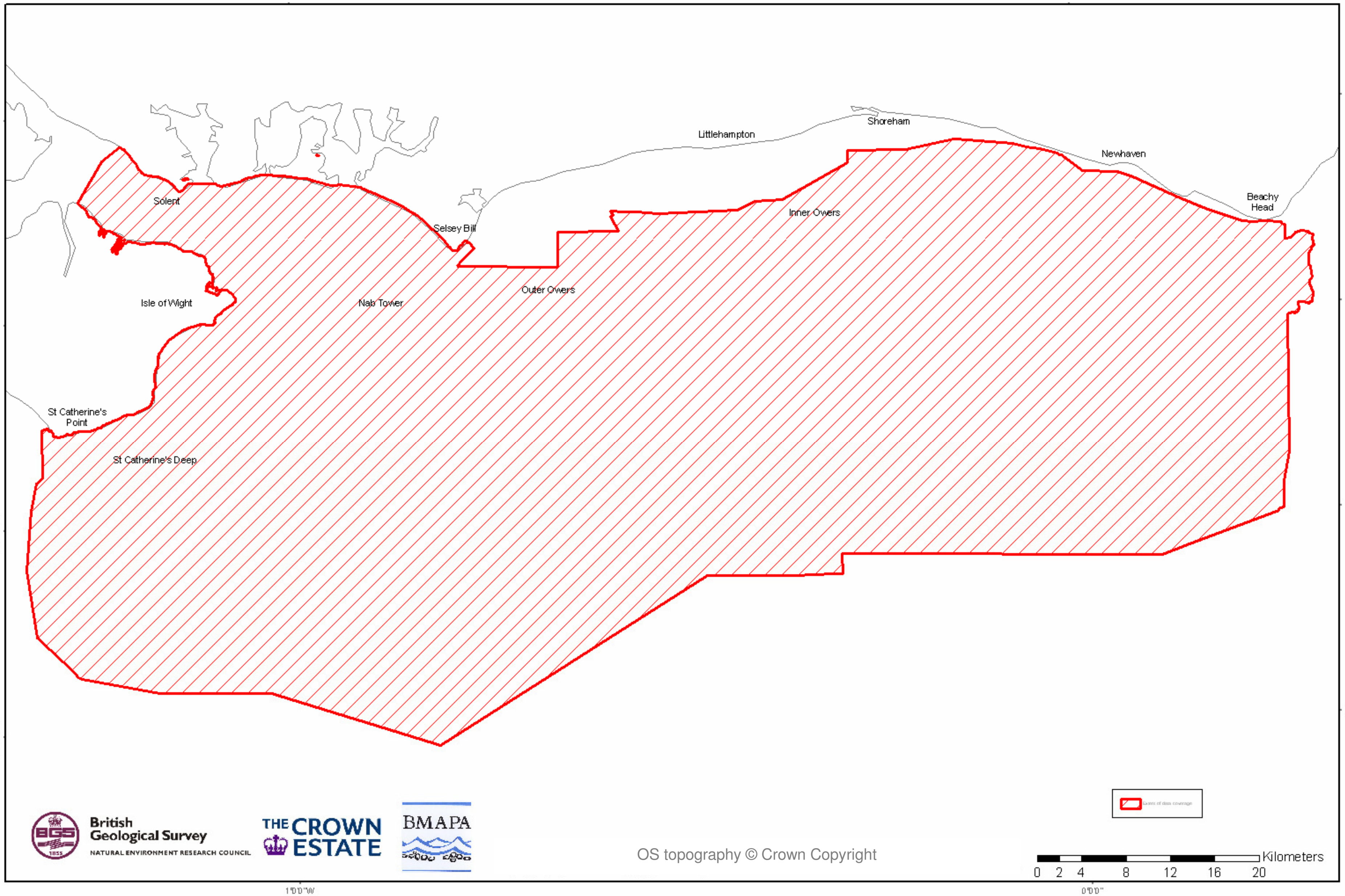


Figure 1: Location of study area showing mapped limit of aggregate industry data and interpretations

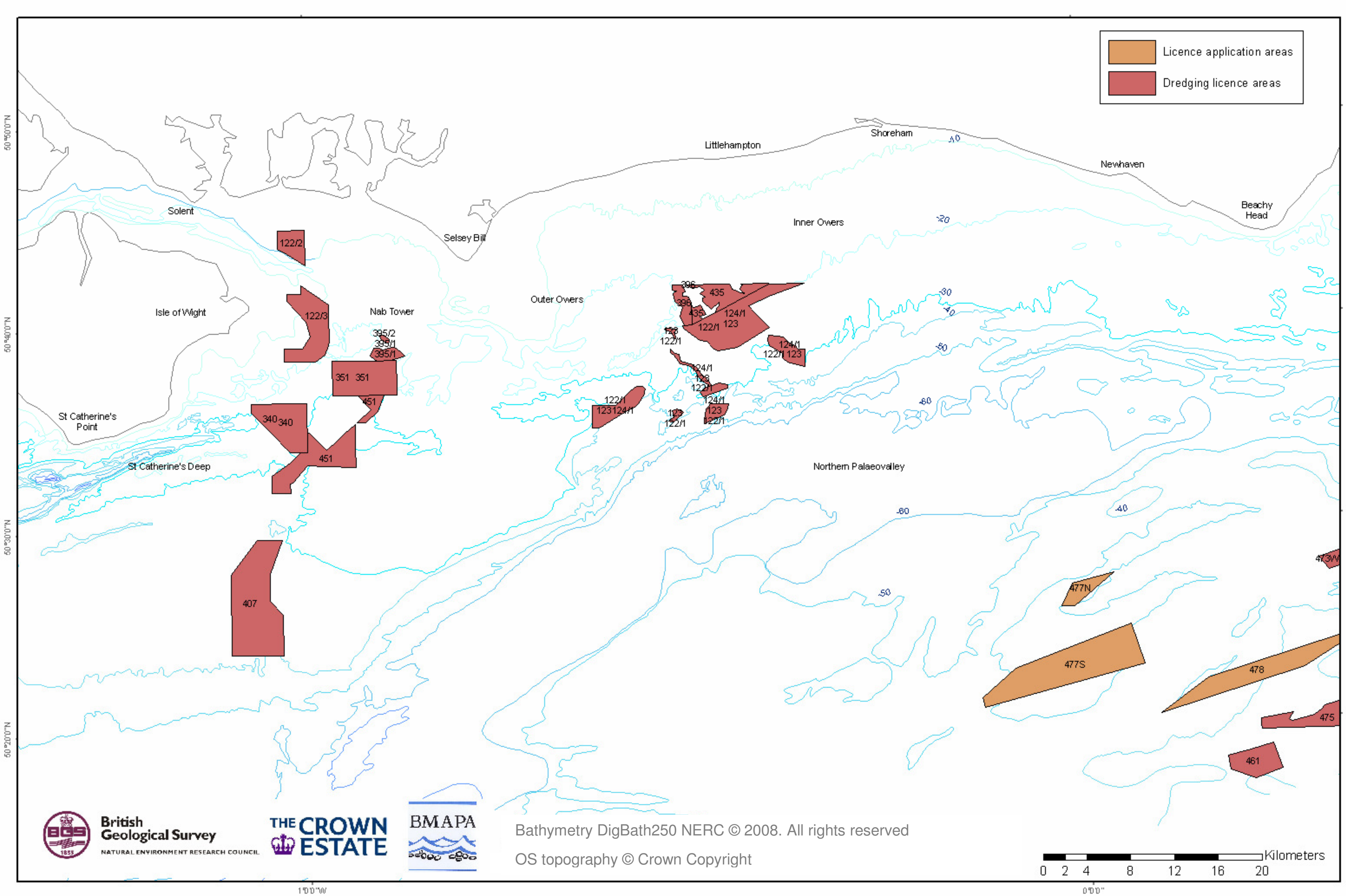


Figure 2: Dredging licence areas.

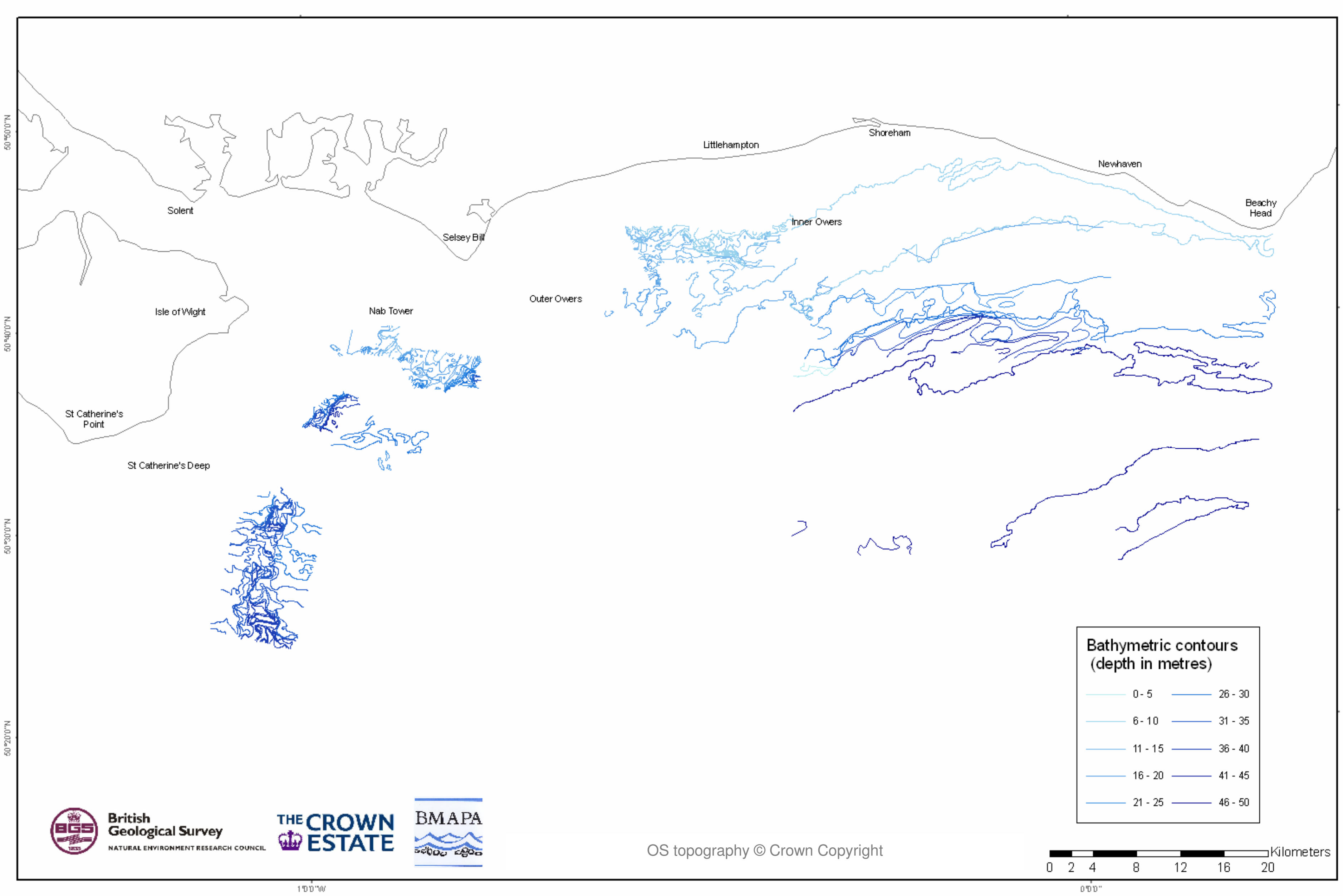


Figure 3: Aggregate industry bathymetric data: All available contours.

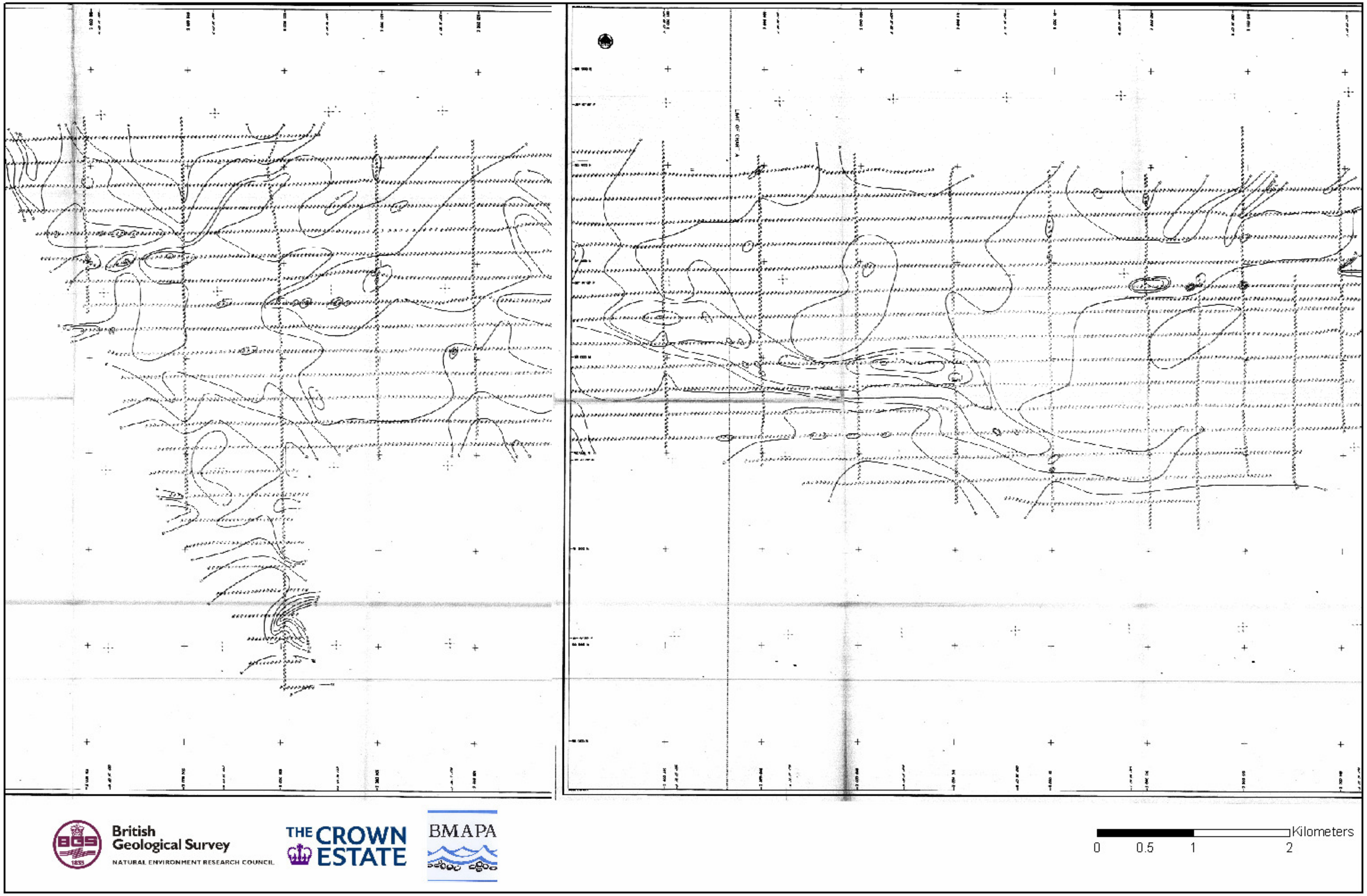


Figure 4: Example of bathymetric data from an aggregate report.

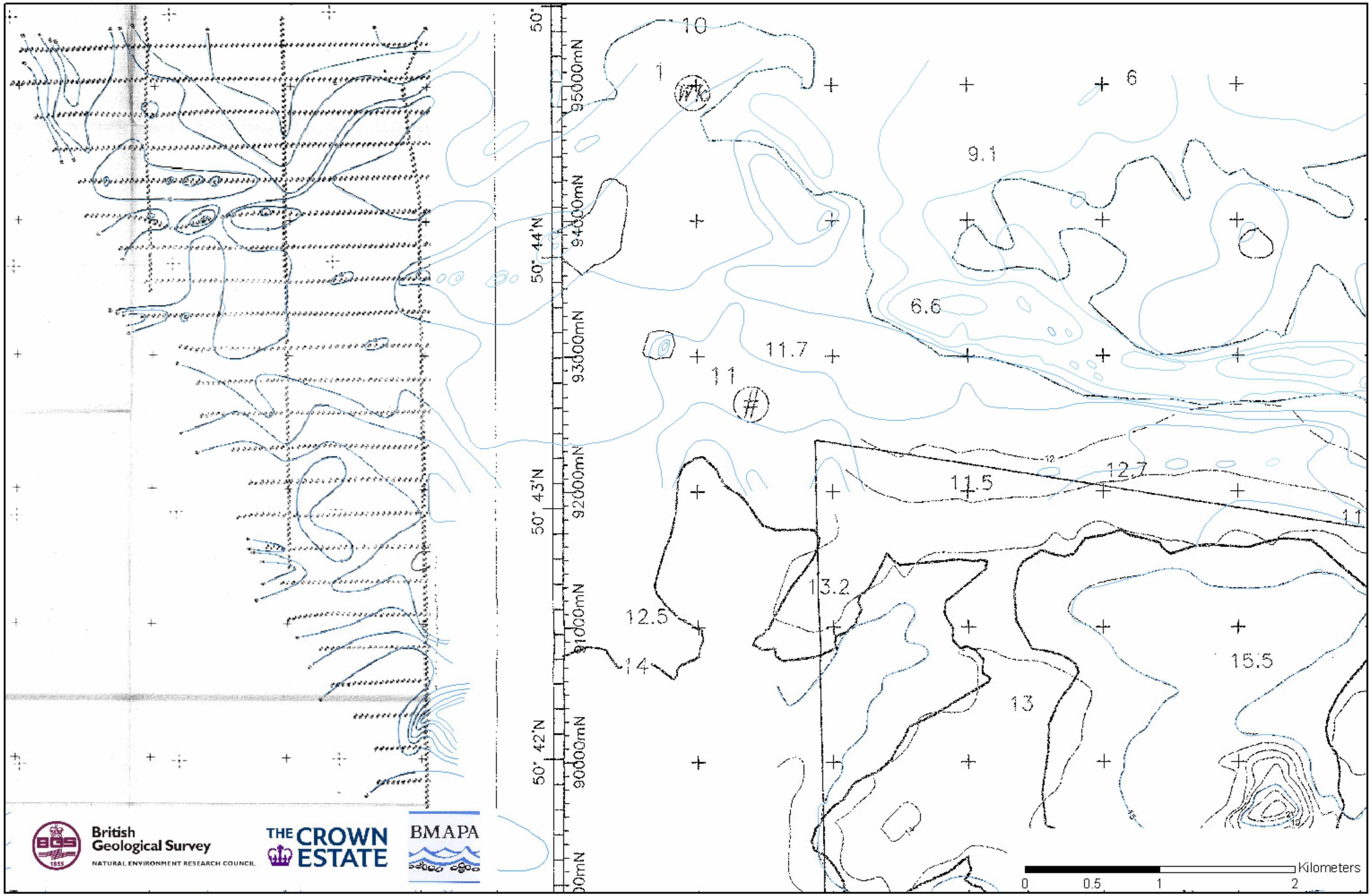


Figure 5: Example of bathymetric data overlap.

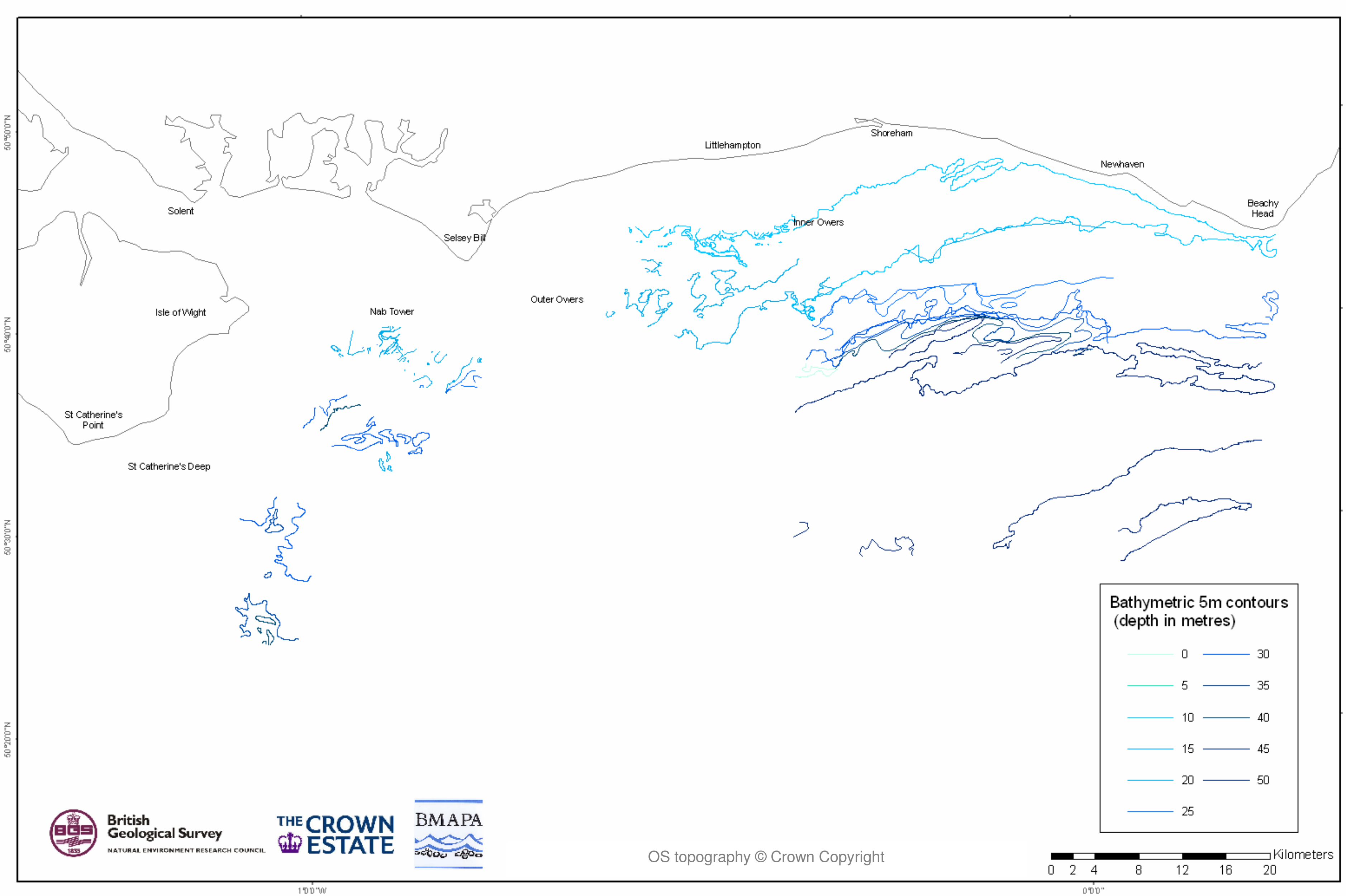


Figure 6: Aggregate industry bathymetric data: 5m contours.

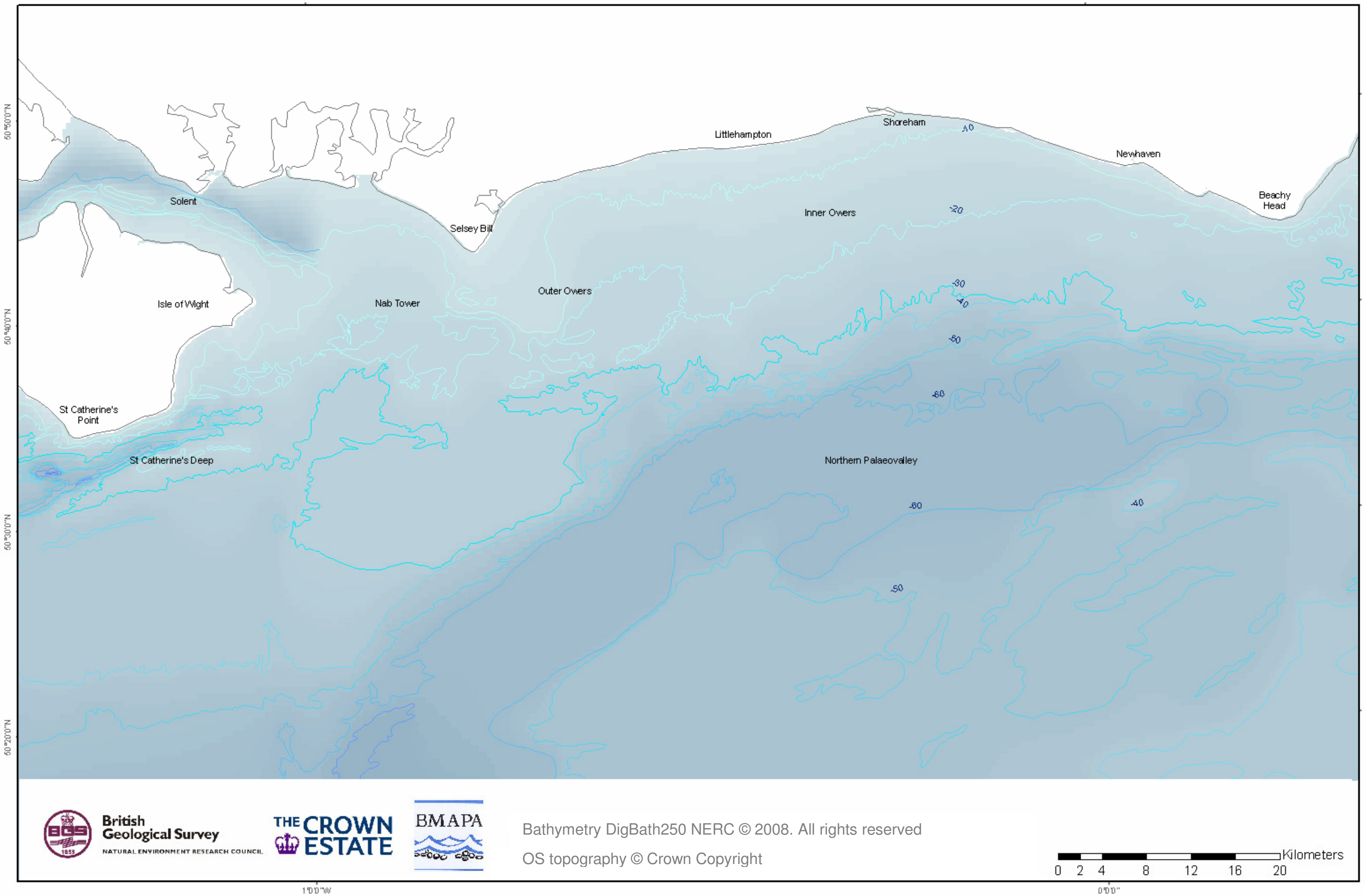


Figure 7: BGS DigBath250 bathymetry.

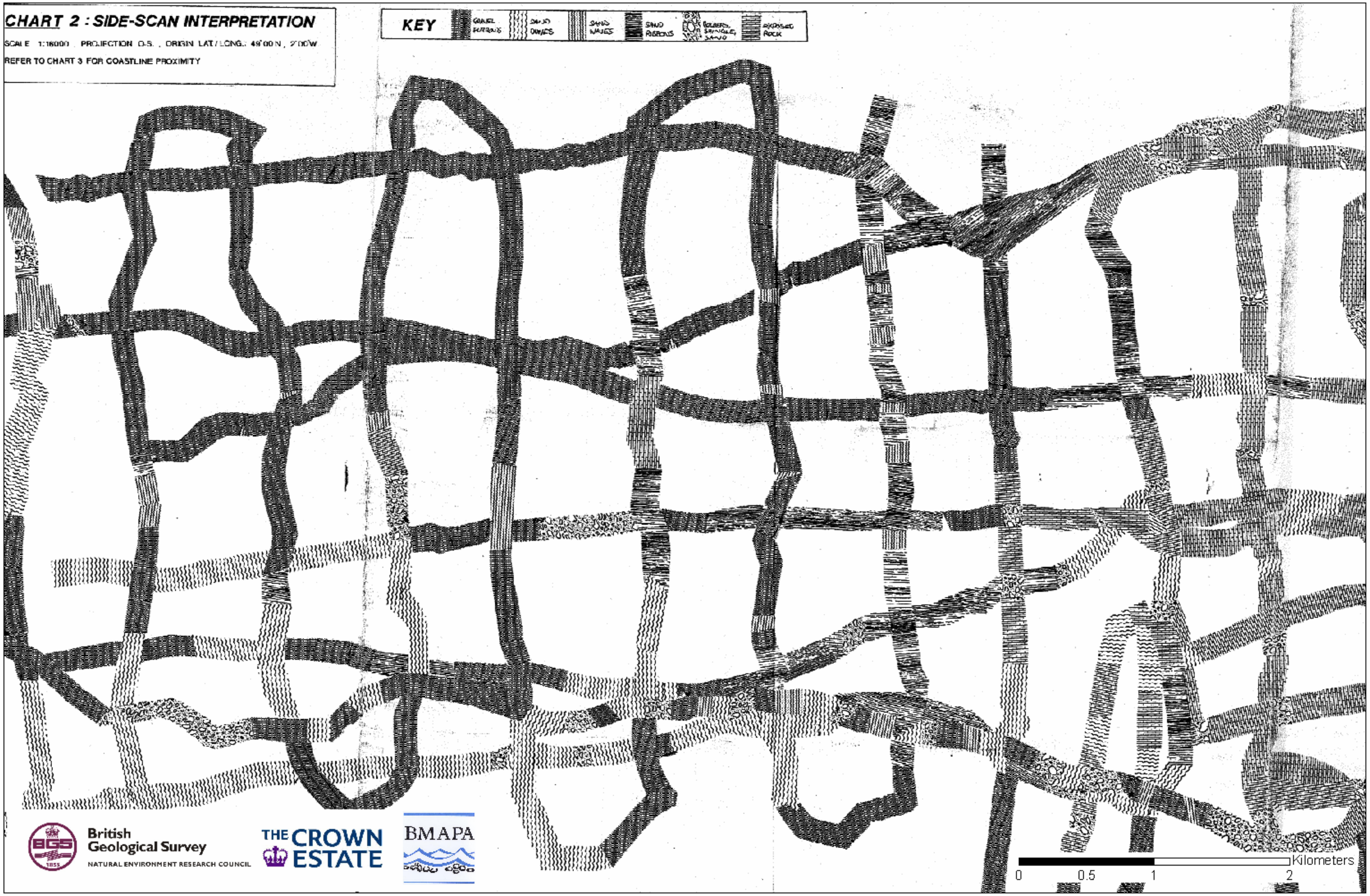


Figure 8: Example of side scan sonar interpretation from an aggregate report.

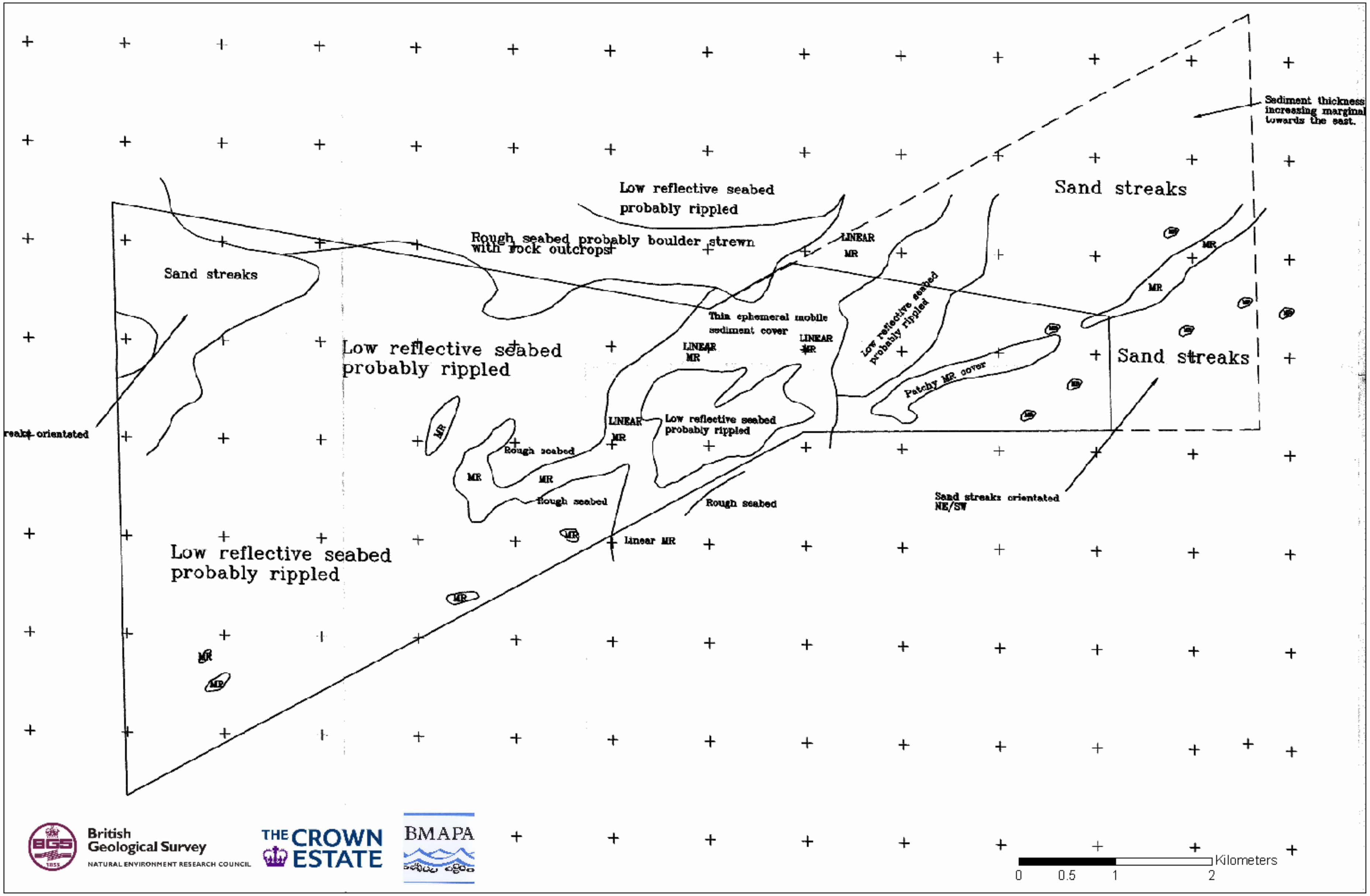


Figure 9: Example of bedform interpretation from an aggregate report.

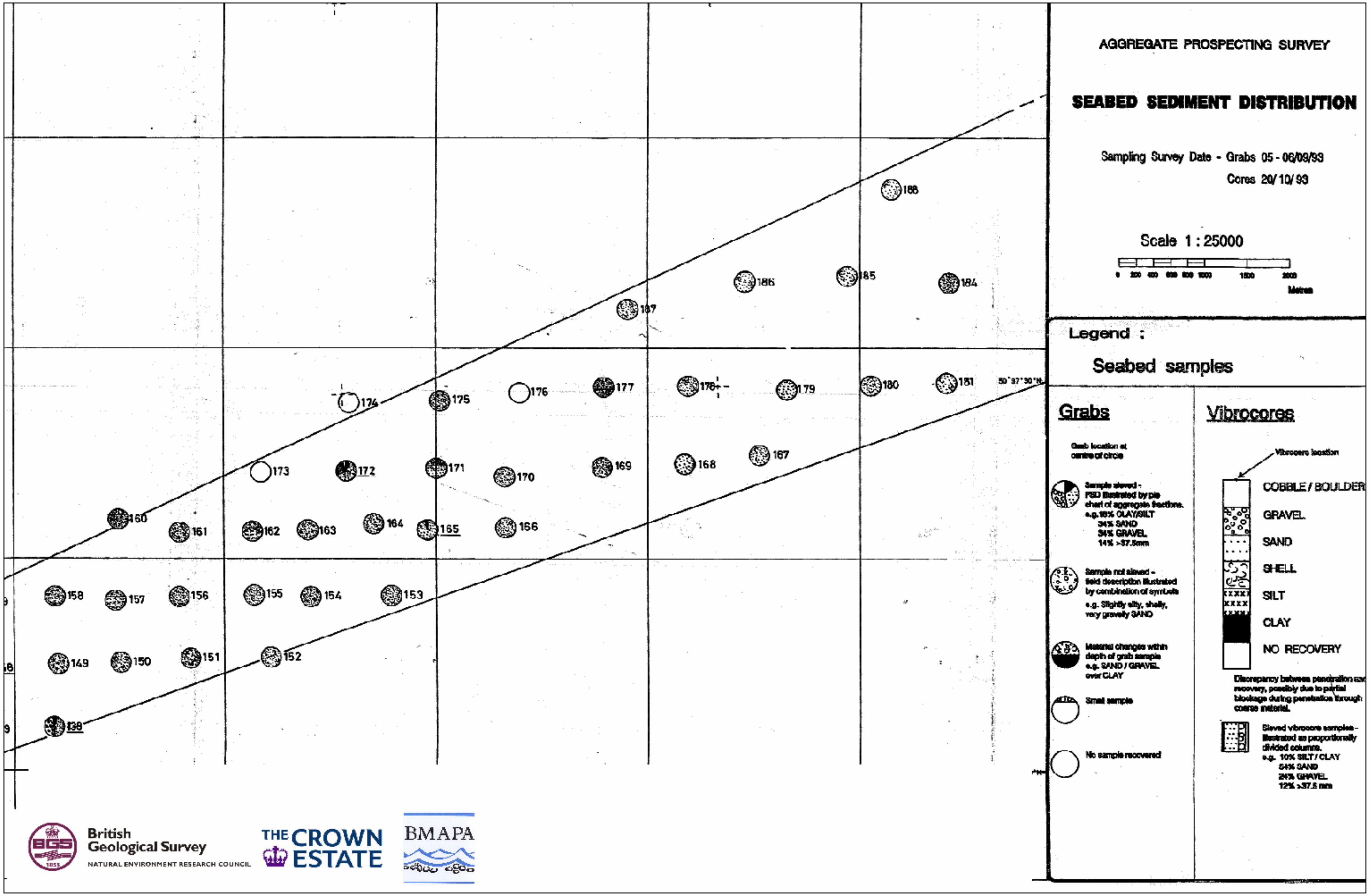


Figure 10: Example of sea bed sediment data from an aggregate report.

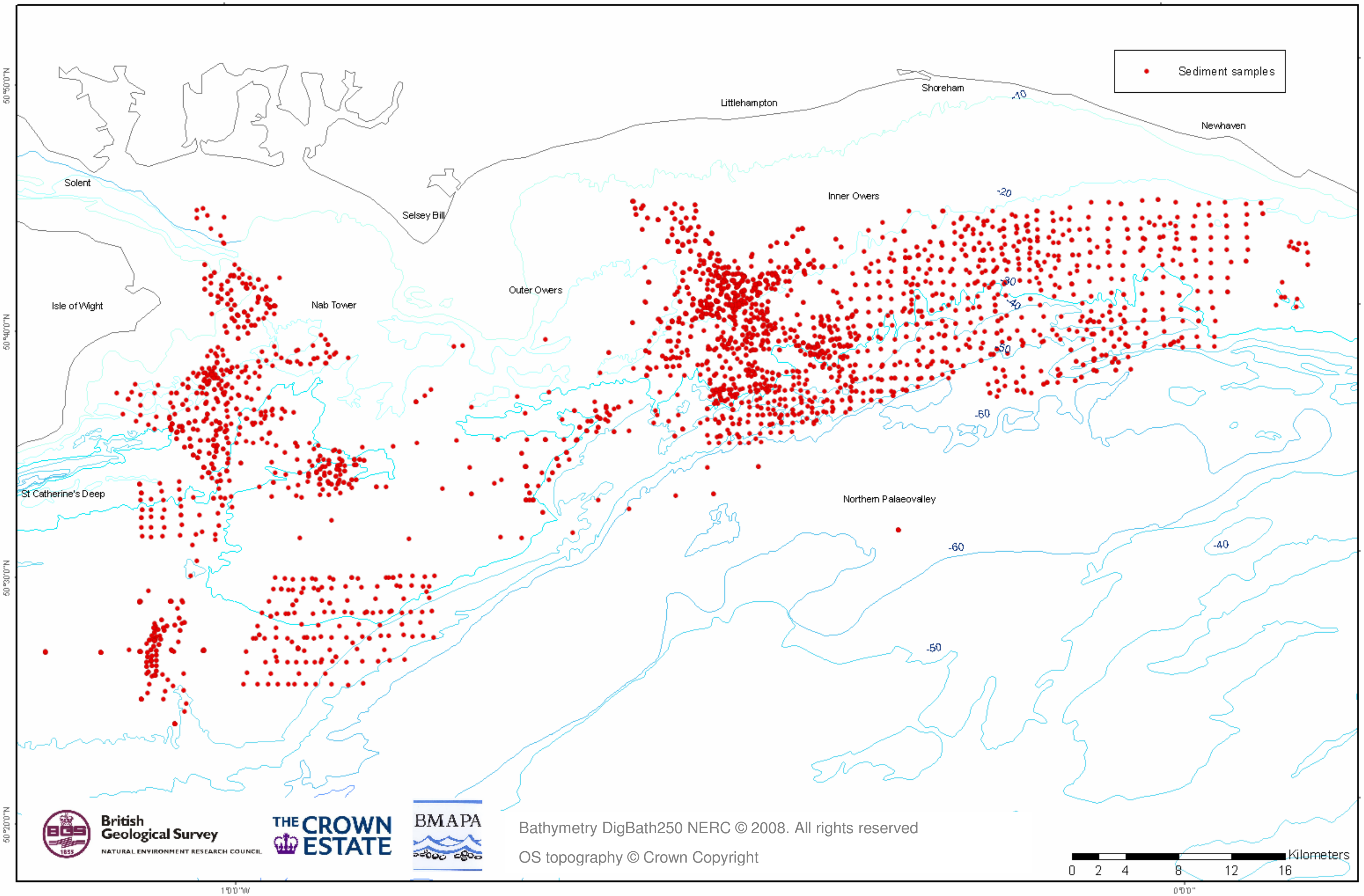


Figure 11: All sediment sample locations from aggregate reports.

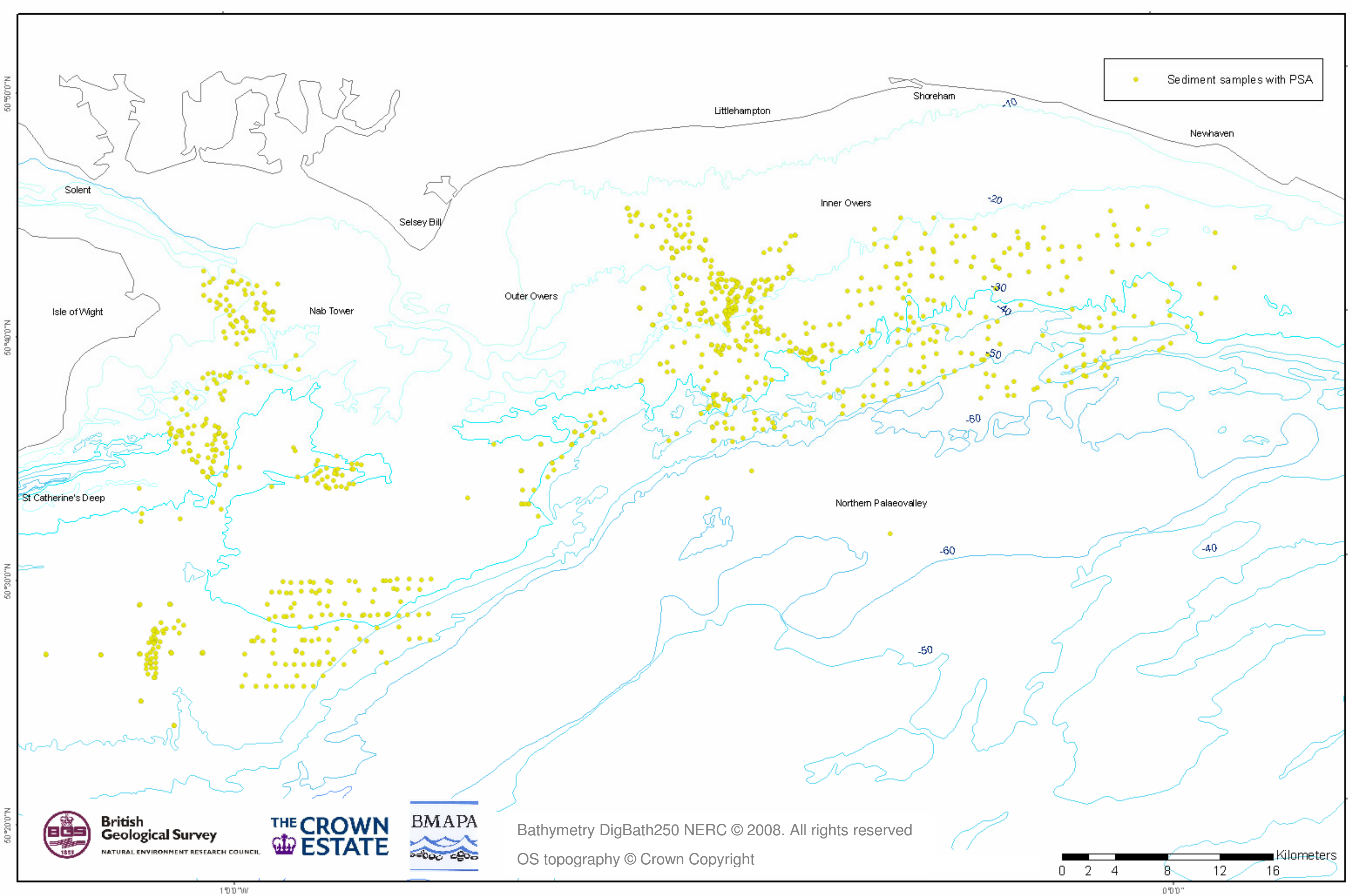


Figure 12: Sediment samples with particle size analysis (PSA).

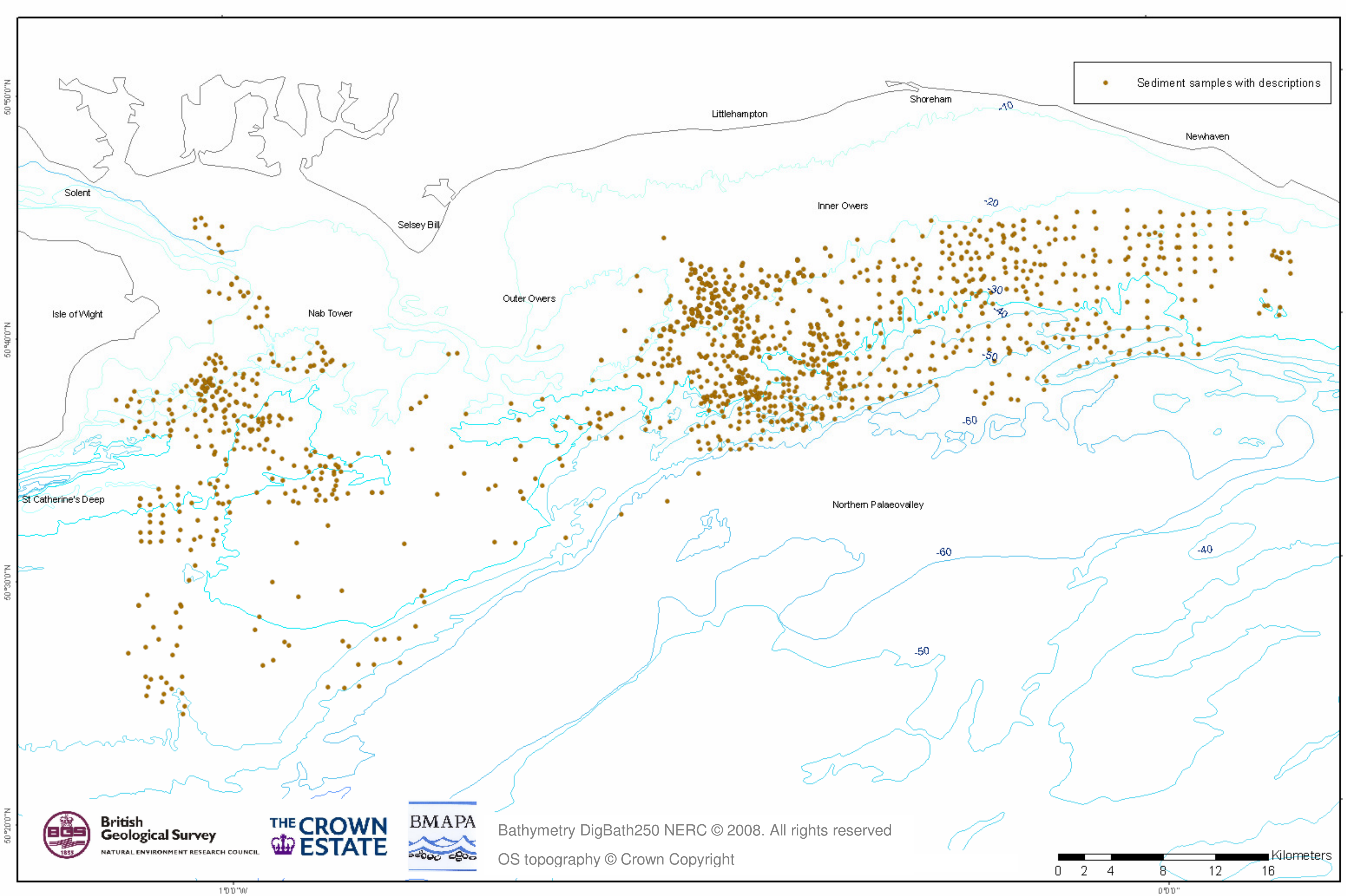


Figure 13: sediment samples with descriptions.

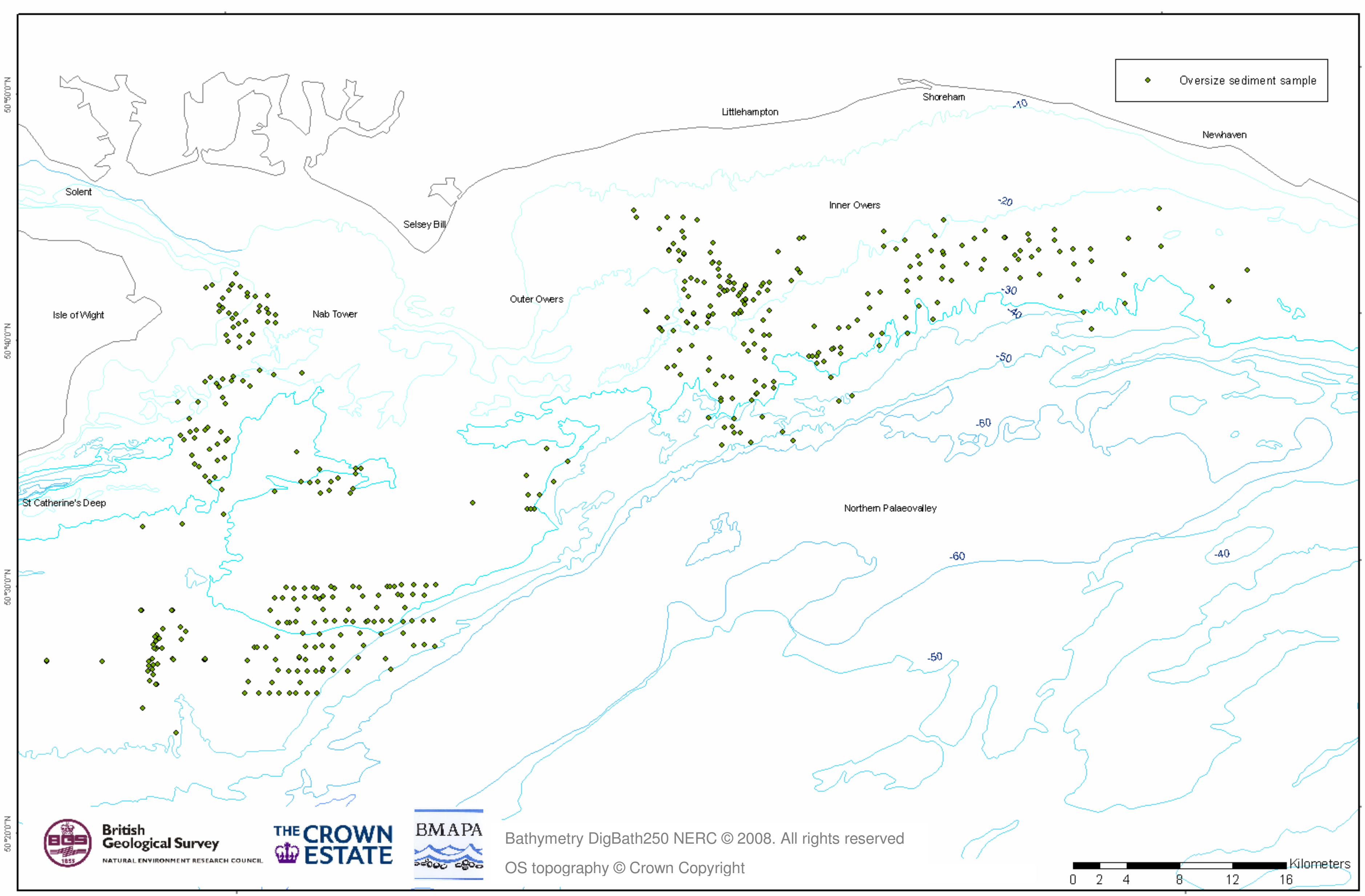


Figure 14: Samples with oversize sediment (>37.5mm).

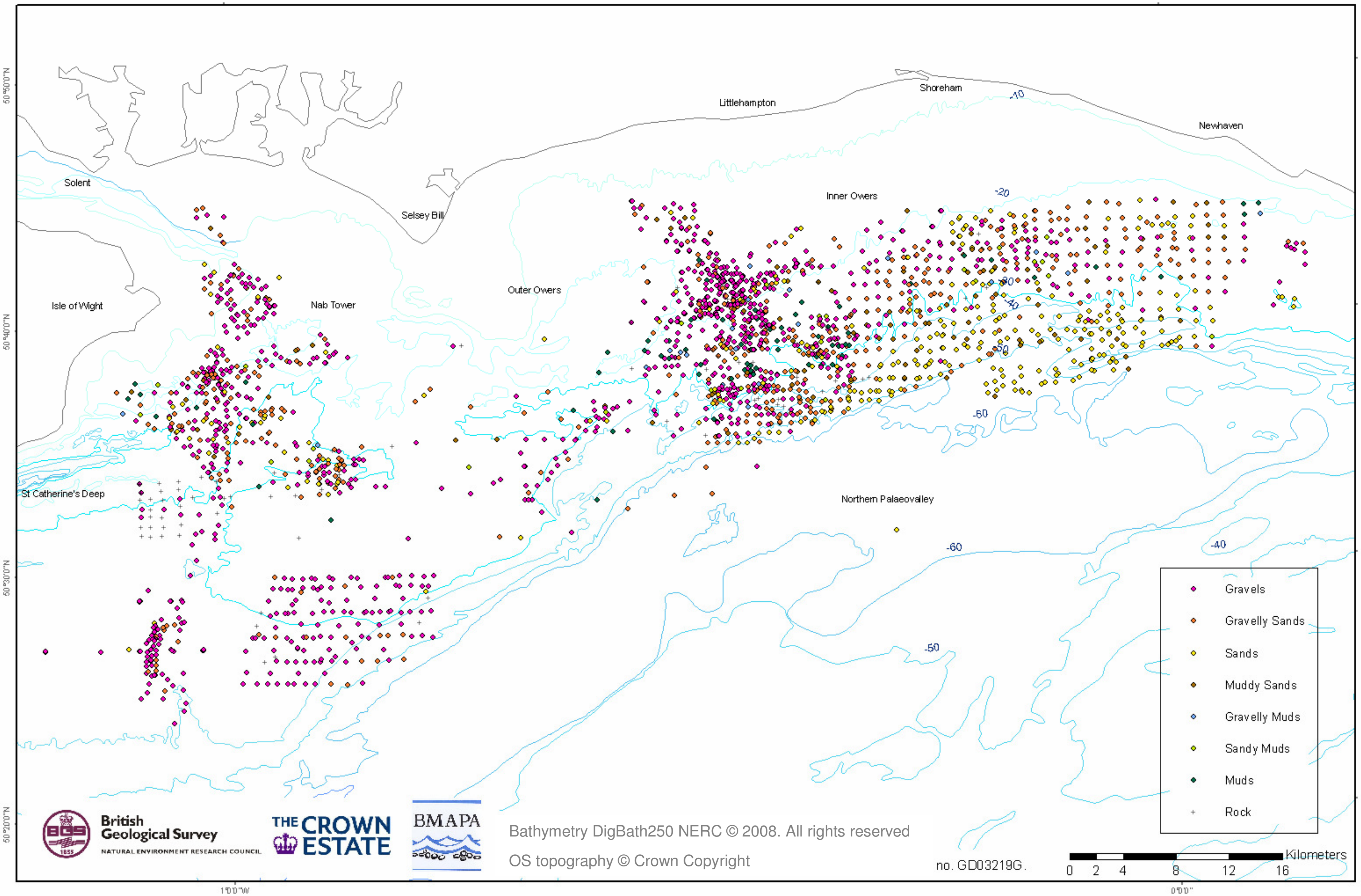


Figure 15: Sediment samples – Modified Folk classification.

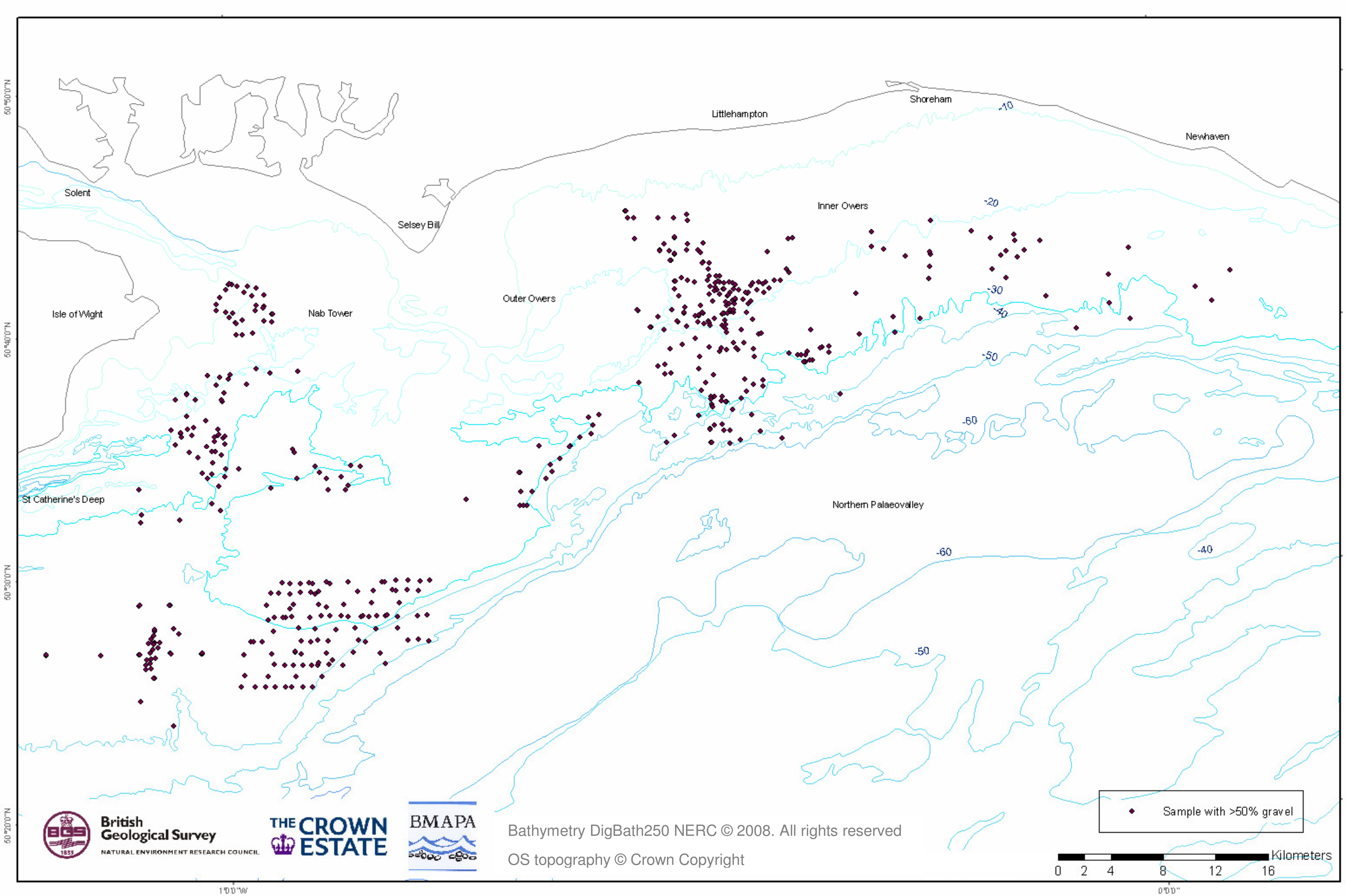


Figure 16: Sediment samples with gravel content >50% from PSA analysis.

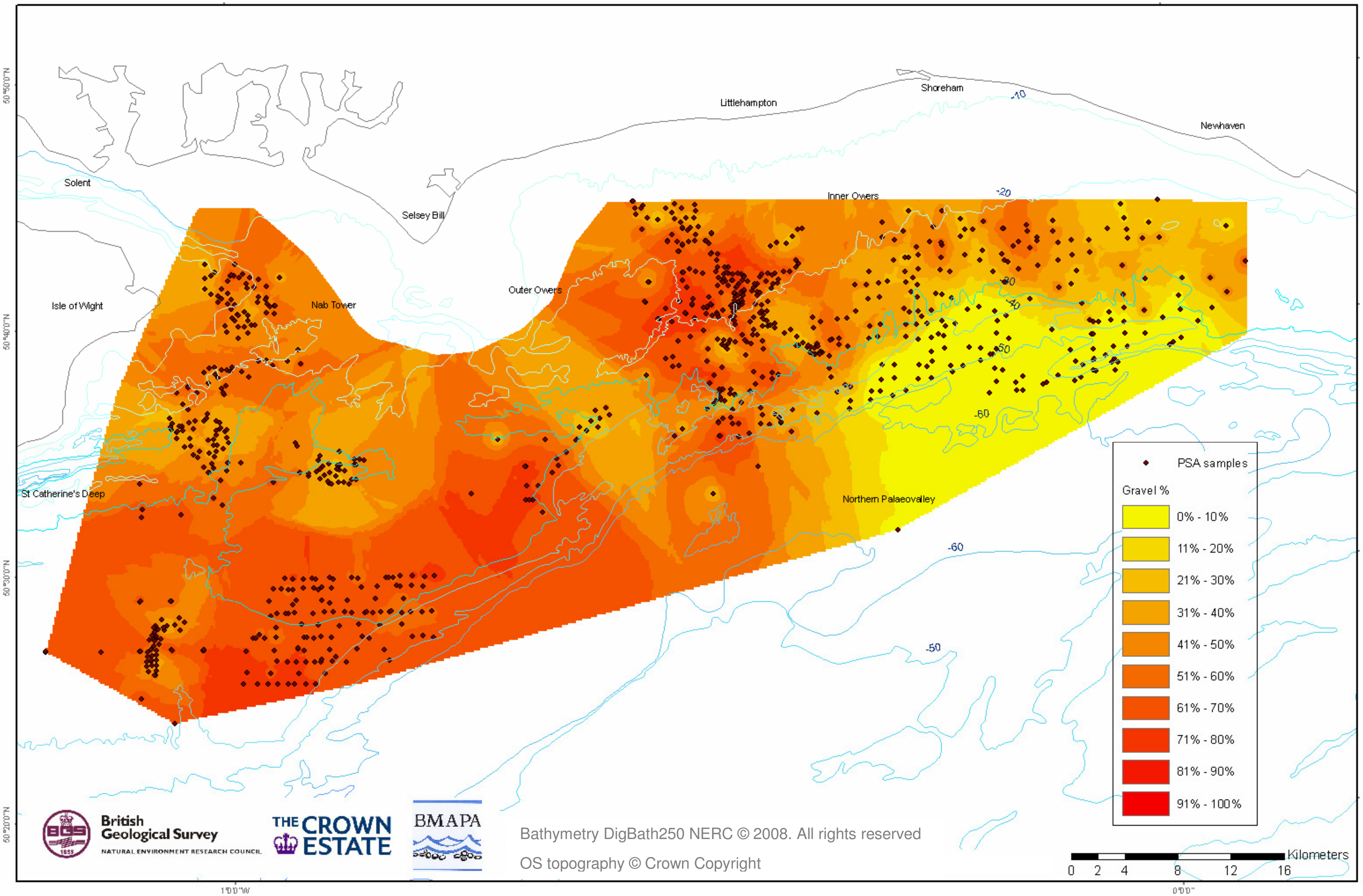


Figure 17: Percentage gravel distribution by Inverse Distance Weighting (IDW) – PSA data.

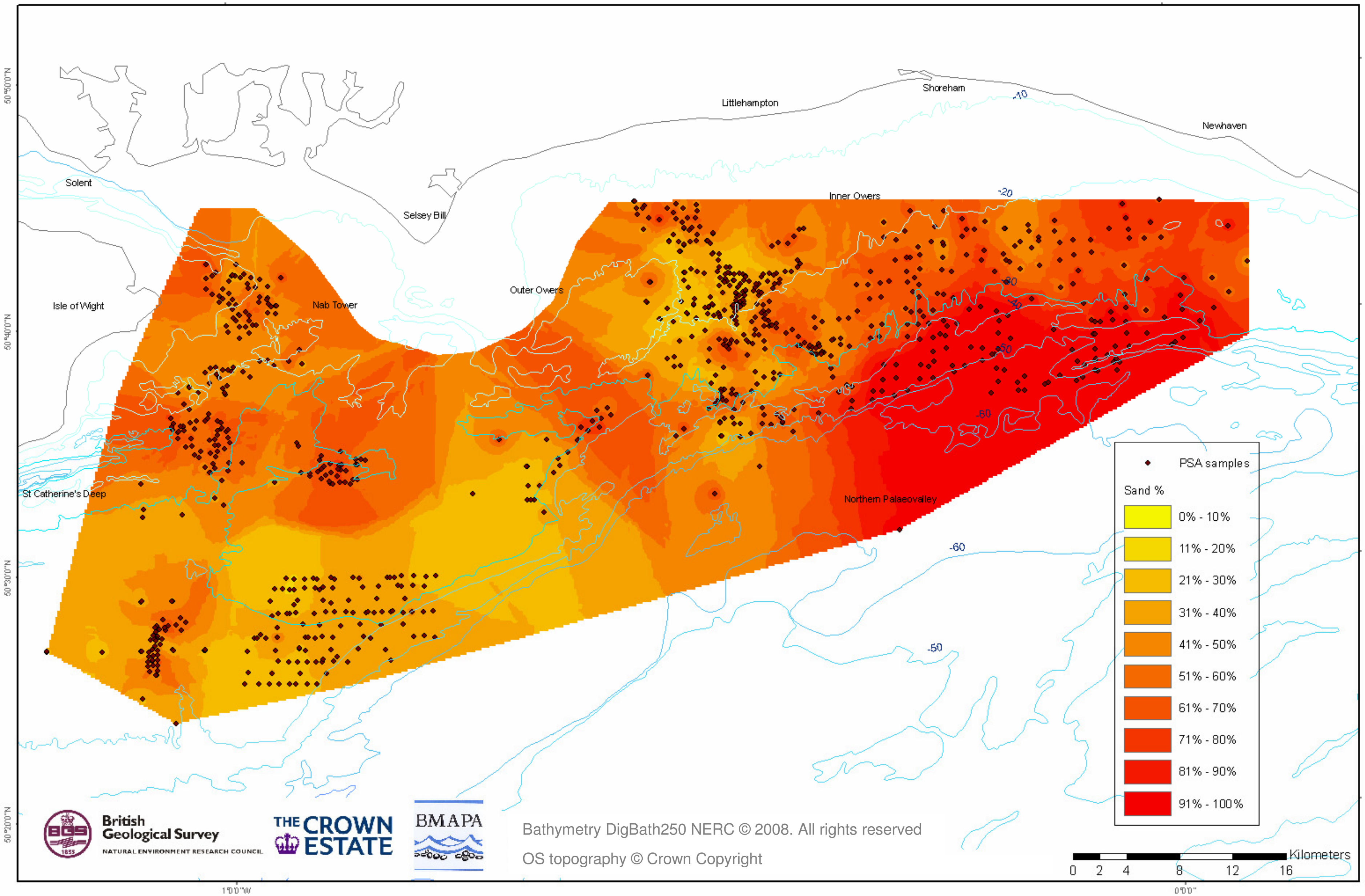


Figure 18: Percentage sand distribution by Inverse Distance Weighting (IDW) – PSA data.

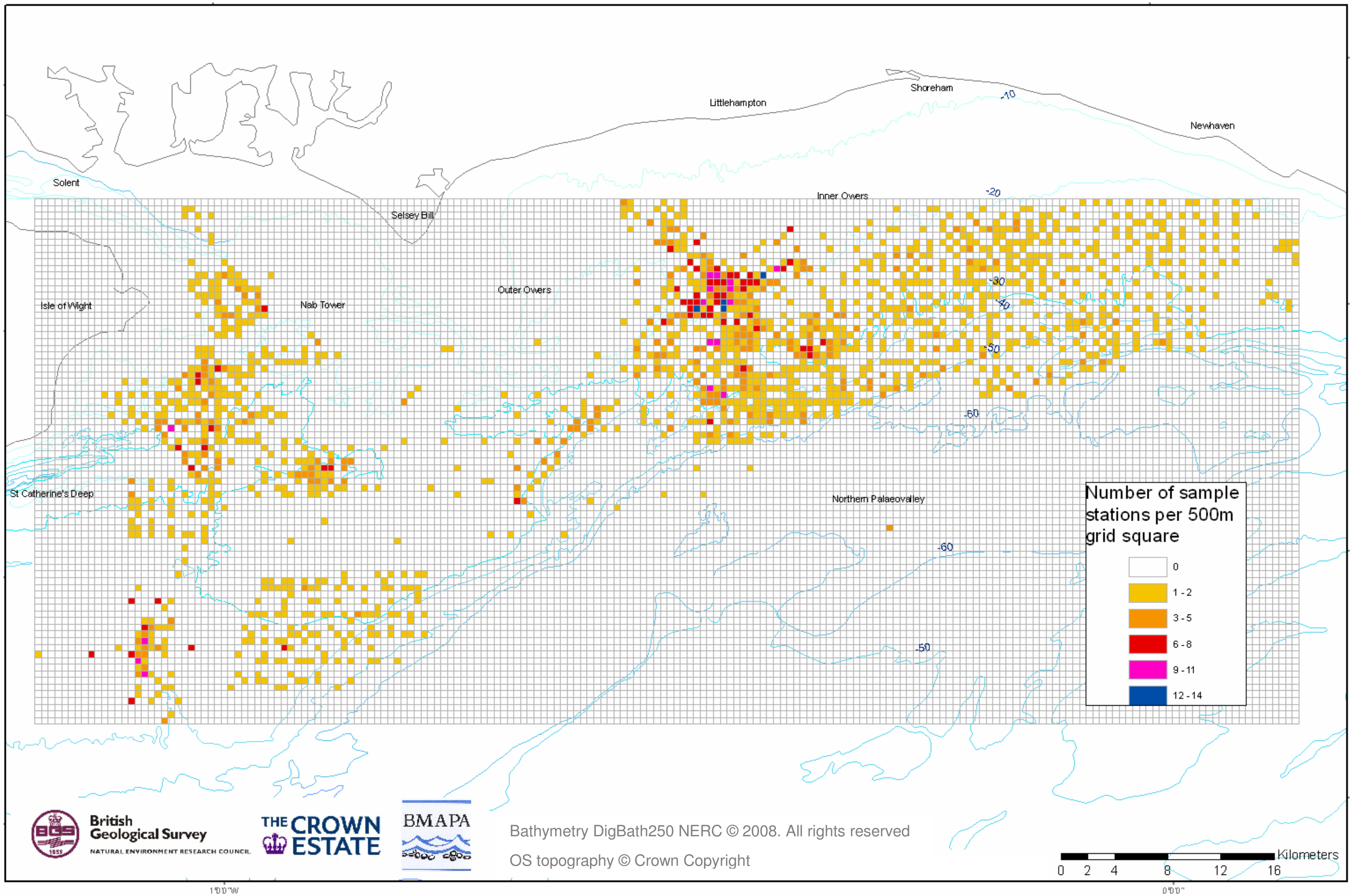


Figure 19: Gridded sample station density (500m grid).

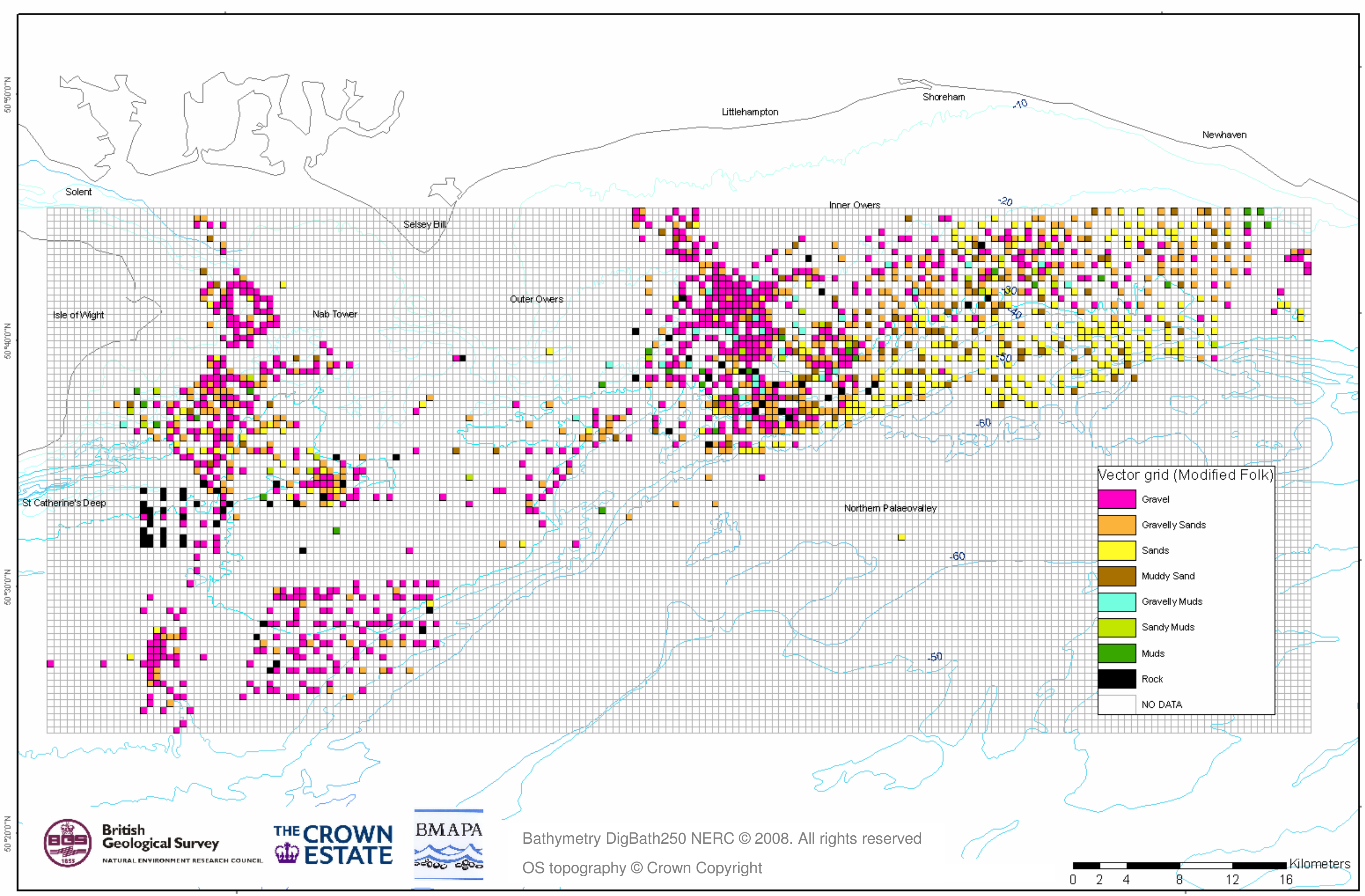


Figure 20: Gridded distribution of sea bed sediments (all sample locations).

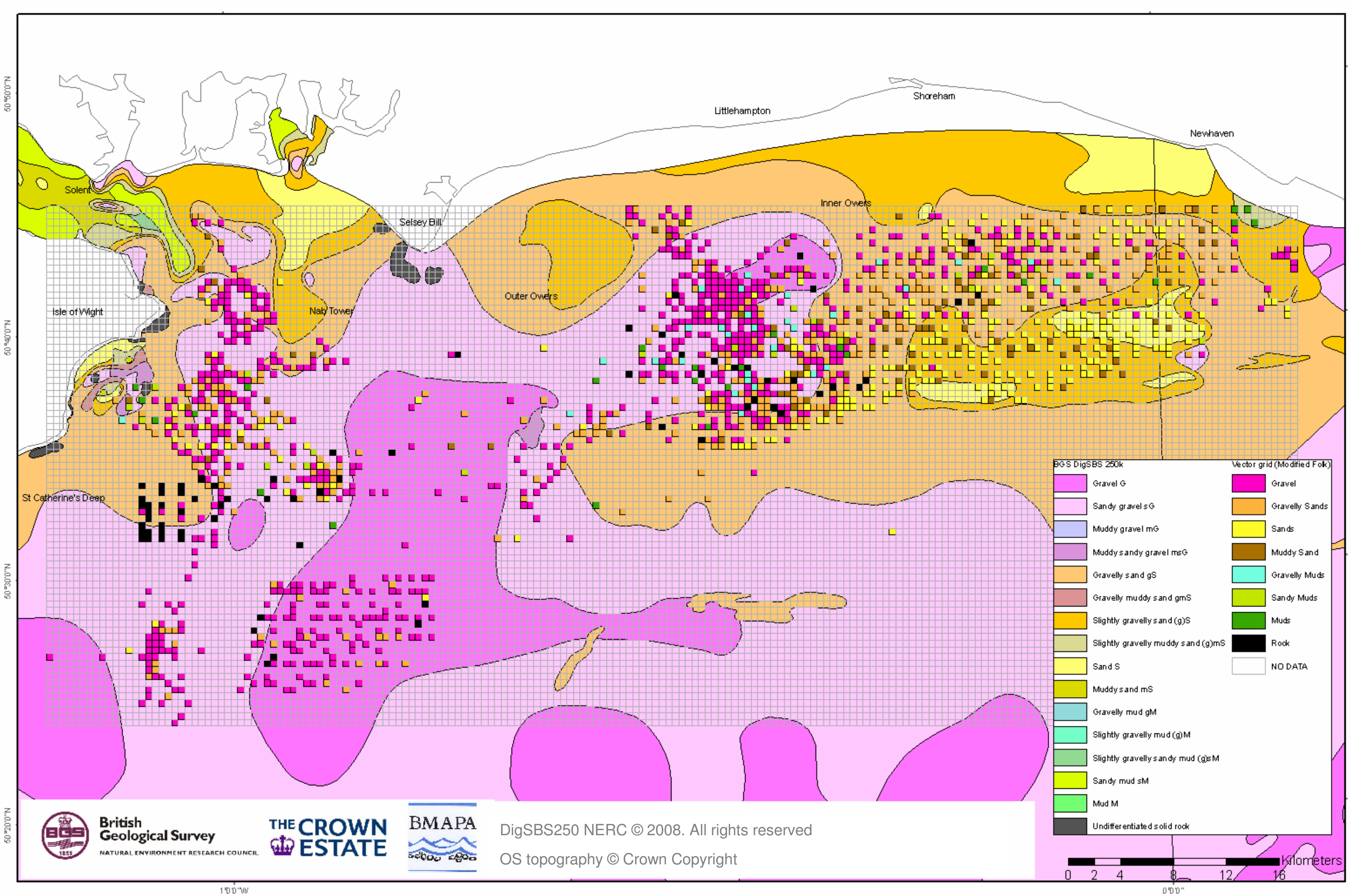


Figure 21: Gridded distribution of sea bed sediments overlain on BGS sea bed sediment DigSBS250 map.

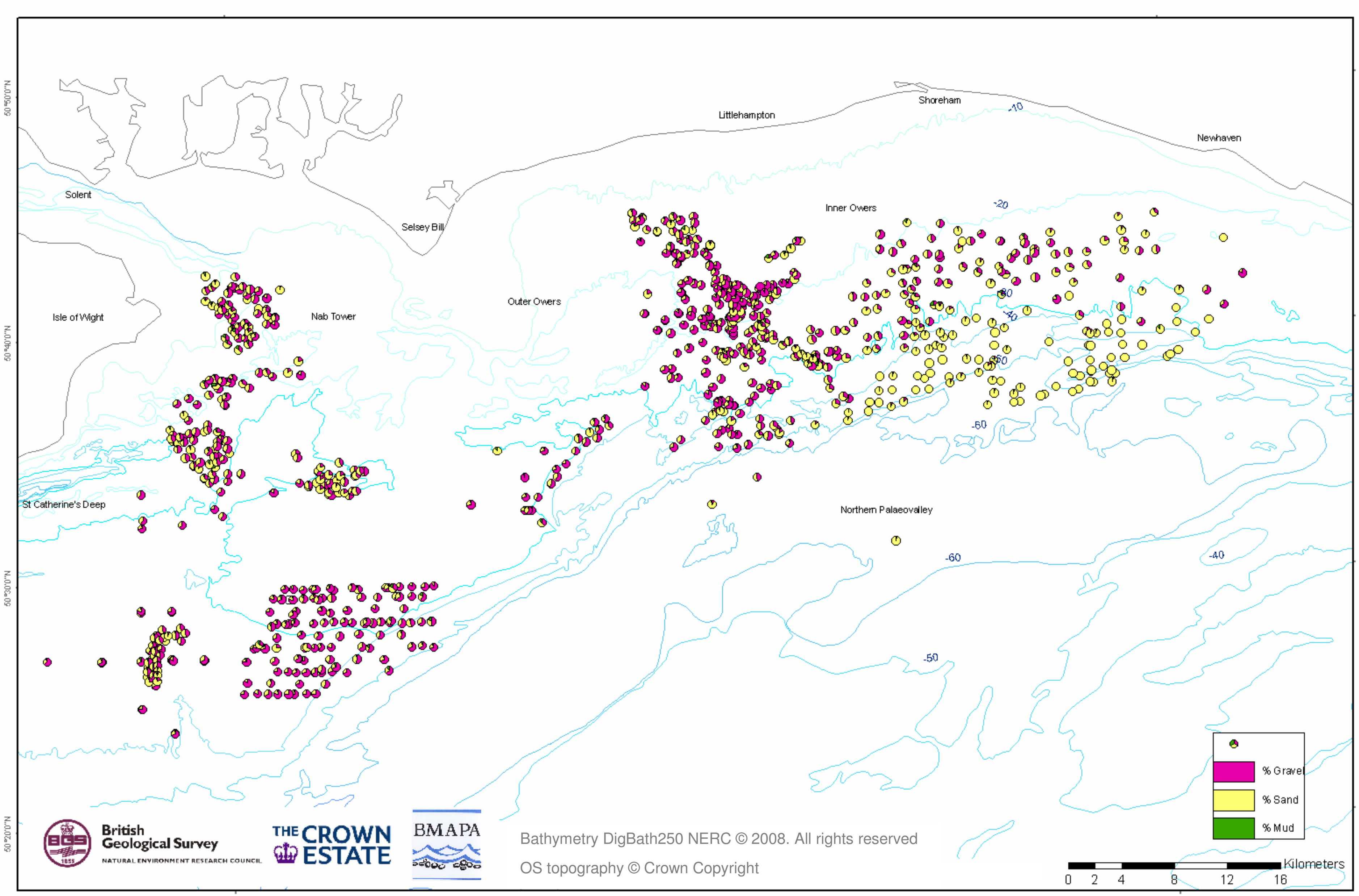


Figure 22: Mud/sand/gravel pie chart for sea bed sediment samples with PSA data.

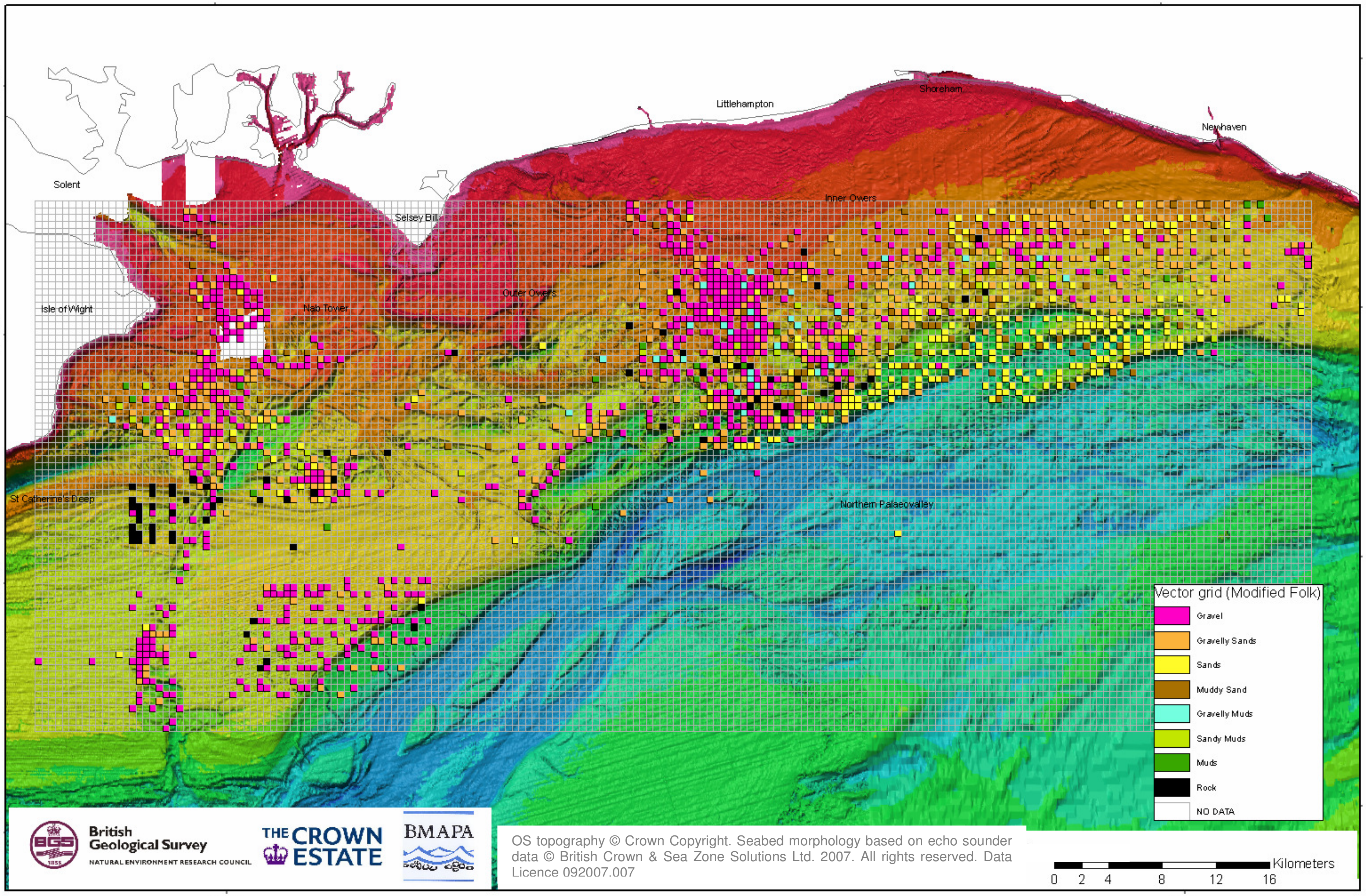


Figure 23: Gridded distribution of sea bed sediments overlain on sea bed morphology model.