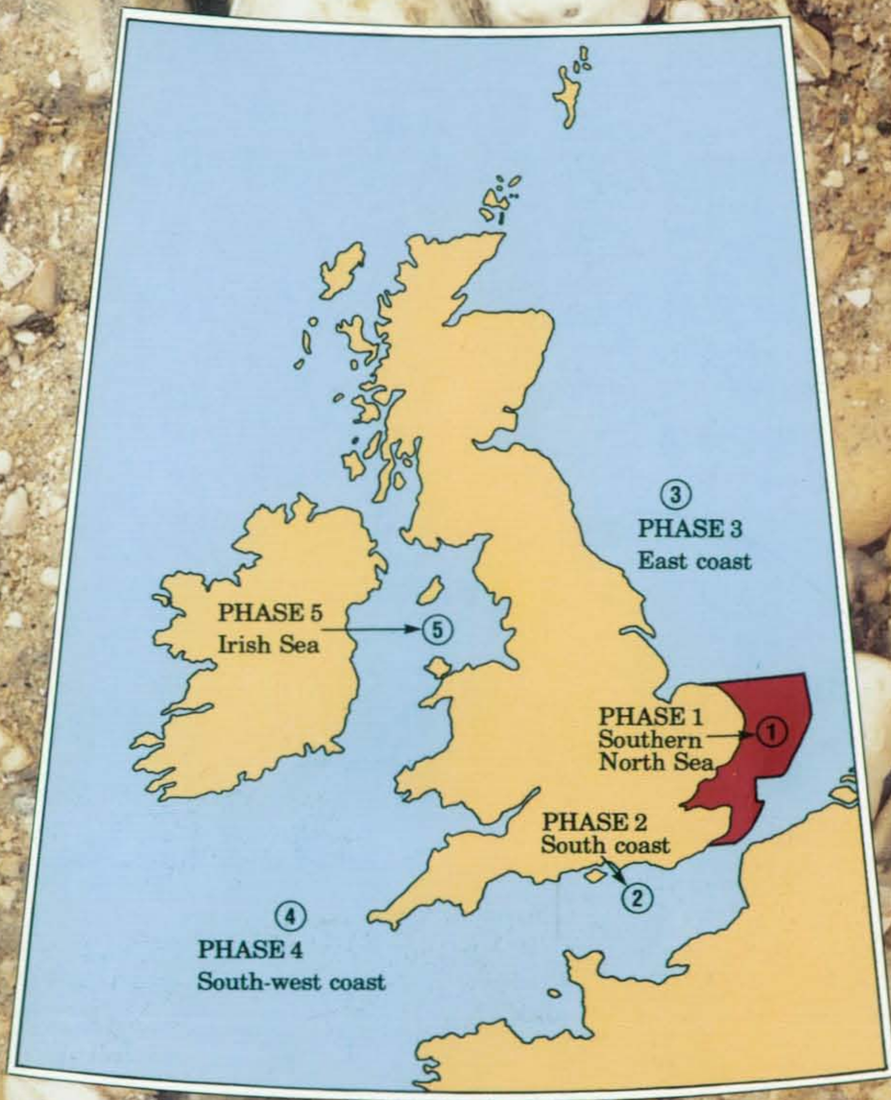
Marine Aggregate Survey Phase 1

Southern North Sea



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BRITISH GEOLOGICAL SURVEY

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Marine Aggregate Survey Phase 1

Southern North Sea

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1. Introduction

Marine sand and gravel meet approximately 10-15% of the demand for aggregate in England and Wales, but in South East England the contribution is nearer 20%. It is declared government policy (DOE Circular 21/82) to encourage the use of marine aggregates wherever possible and in order to assist mineral planning by central and local government it is clear that information on offshore sand and gravel resources is required.

A considerable amount of information on the surface and sub-surface geology of the UK continental shelf is available within the British Geological Survey (BGS) and the Crown Estate Commissioners (CEC) have commissioned BGS to undertake a review of all available data on marine aggregate resources.

This report gives the results of the data assessment of the Southern North Sea area which forms Phase 1 of the CEC research programme. The area covered in this report is from 51°-53°N and covers UK waters east of 1°E. Further areas of the continental shelf off England and Wales are scheduled for appraisal in later stages of the programme. Phase 1 also forms an essential first stage in a more detailed resource assessment research programme to be funded by the Department of the Environment (DOE). This will aim to evaluate the origins, distribution and quality of marine aggregate resources in a trial area off the East Anglian coast.

This study is based on the interpretation of information from the BGS data base supplemented by resource data acquired from dredging industry prospecting survey reports. Additional data was extracted from Site Investigation Reports, Admiralty Surveys and other minor sources.

The Southern North Sea is probably the most extensively researched section of the European Continental Shelf and the large amount of available sea bed sediment data reflects the academic and commercial interest shown in this area. Other areas of the UK continental shelf have not been as extensively sampled.

The aim of the report is to summarise the general sea bed geology of the area and to indicate the approximate location of potential sand and gravel resources. The likely quality and quantity of the deposits are also considered but these will be more fully understood following the seismic and sampling survey to be commissioned by DOE. Seven maps at 1:250,000 scale accompany the report.

Map 1	Bathymetry
Map 2	Bedforms
Map 3	Sample Points
Map 4	Sea Bed Sediments and underlying geology
Map 5	Surface distribution of coarse aggregate (gravel)
Map 6	Surface distribution of fine aggregate (sand)
Map 7	Licensed Dredging Areas

2. Sources of Data

Bathymetry Data

Bathymetric contours at 10 m intervals have been compiled from Hydrographic Department (MOD) data (Map 1). The contours represent depths below Lowest Astronomic Tide (LAT).

Tidal Current data

The tidal current data shown on Map 1 comes from a variety of sources (see Appendix) and was obtained from the Marine Information and Advisory Service (MIAS) of the Institute of Oceanographic Sciences and from published Admiralty Charts.

Bedform data

Bedform data has been compiled from two main sources.

a) Hydrographic department data is very detailed in some parts of this area. Individual sandwaves which may attain heights of over 10 m can be visible even on the relatively small scale of the surveys and crest orientations for large sandwaves can be easily seen. The outlines of sandbanks in the study area have also been delineated primarily from bathymetric data.

b) Echo sounder and high resolution reflection profiling records from several thousand kilometres of traverses by BGS in the area have been used to delineate the major areas where sandwaves occur. Spacing of survey lines is typically between 2 and 5 km.

This data has also been used to indicate the maximum values of sandwave height shown on the map (Map 2).

BGS has a limited amount of sidescan sonar data over part of the area which can be used to aid the mapping of sediment boundaries and bedforms and the Hydrographic Department has good sidescan coverage for certain limited areas, mostly shipping lanes and harbour entrances. Use of the latter is limited by its restricted status.

However due to time constraints these data have not been incorporated but it is not thought that their exclusion significantly alters bedform distributions illustrated , given the scale of presentation.

Sediment data

The sediment data depicted on the maps of sea bed sediments (Map 4), coarse aggregates (Map 5) and fine aggregates (Map 6) comes from the following four main sources:

a) British Geological Survey, Marine Earth Sciences Research Programme.

The distribution of sediments and their disposition relative to underlying strata has been discerned from geophysical traverse data calibrated by sampling, coring and drilling. The suite of geophysical equipment used included echo sounder, side-scan sonar, pinger, boomer sparker, airgun, magnetometer and gravitmeter.

The sediment samples collected by BGS in the study area include shipek grab samples, gravity cores and vibrocores. Most cores are 2-3 m long but some are up to 6 m in length. The data used to compile the maps in this report originate almost entirely from the grab samples with occasional material derived from the top 5 cm of a core.

The sediment samples were analysed using the methods described elsewhere in this report.

b) University and Polytechnic data

Large numbers of samples have been collected in the area by the City of London Polytechnic (mostly south of 52° 20'N and west of 1°E) and the University of East Anglia (nearshore areas of Suffolk and Norfolk).

Most of these sediment samples were analysed by methods similar if not identical to the BGS samples and were obtained from a mixture of grab types (including Shipek and Van Veen) together with small dredge sampling equipment.

c) Institute of Oceanographic Sciences (IOS)

IOS have collected samples in two main areas within the study area:

i) the Sizewell-Dunwich Banks area

ii) in the vicinity of Smith's Knoll sandbank

These samples were obtained by a mixture of grab and coring devices and were analysed using methods similar to those adopted by BGS. The Smith's Knoll sample analyses were performed in BGS laboratories.

d) Dredging company data

This data was obtained from commercial prospecting reports provided by the Crown Estate Commissioners for the purposes of this study.

The data is concentrated on areas with gravelly sediments.

The methods used to obtain these data include grabs, coring devices (primarily the AMdril) and underway sampling using a commercial dredger.

Sediment data obtained from underway dredging have not been considered as the method of retrieval is believed to distort the relative abundance of grain-size fractions.

Samples obtained during the top 10 cm of AMdril coring have been used together with any grab sample data.

Analysis methods are unknown and the presentation of results differ from the other data sources in several respects (see later discussion).

e) Other data

The Hydrographic Department (MOD) collect sediment samples during bathymetric surveys. These samples are small (<1 kg) and are housed at their British Museum (Natural History), where they are made available for academic research. They have not been utilised in the compilation of this report.

3. Sea bed sediment classification and analysis of BGS samples

The classification of sea bed sediments follows the scheme devised by Folk (1954) using a ternary diagram with the three end members Gravel, Sand and Mud (Figure 1). The definitions used by Folk for these end members are widely used by geologists but differ to those used by the extractive industry.

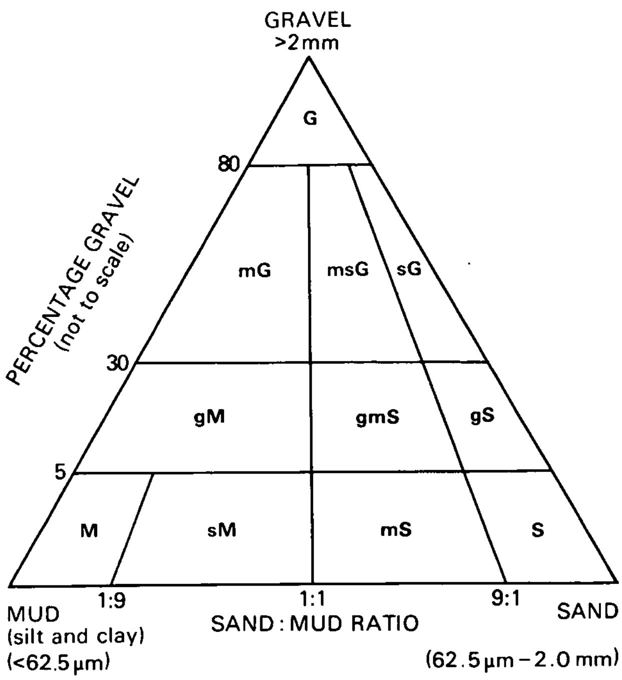

Figure 1 Sediment classification used in this report. (Modified after Folk, 1954).

Gravel is defined here as grains >2 mm (cf. >5 mm for 'coarse aggregate' used by industry).

Sand is defined as grains less than 2 mm diameter but greater than 63 um, with mud being less than 63 um (cf. 75 um used as upper limit of 'fines' by industry).

The relative percentages of these end members has been determined using standard sieves to obtain a classification within the triangular plot.

The plot as originally devised by Folk has been modified for the purposes of this report to include fewer categories of sandy or muddy sediments whilst retaining Folk's original categories for sediment with >5% gravel.

In order to yield data of more direct use to dredging industry most samples were additionally sieved through a 5 mm diameter sieve. From this data the percentage of sediment coarser than 5 mm was obtained and plotted separately as contours at 20% intervals (see Map 5).

Carbonate content

The carbonate content deriving from the presence of shell material within the >5 mm fraction of the sediment was determined by manual extraction and weighing.

The data is expressed as a percentage of the >5 mm fraction and the 20% contour considered as the maximum permissible shell content for concreting aggregates (BS 882) is shown on Map 5.

4. Tidal currents

The Southern North Sea is an area of strong tidal currents with peak surface velocities reaching over 1.6 ms^{-1} (3.2 knots) in some southern parts of the study area. The velocities near sea bed are slightly less than surface values but are still generally in excess of 1 ms^{-1} over most of the area (see Figure 2). The presence of such high current velocities is an important factor in the interpretation of the distribution and movement of sea bed sediments in the Southern North Sea. Wave induced currents also have an effect on sediment movement, particularly in relation to longshore drift which will be discussed later.

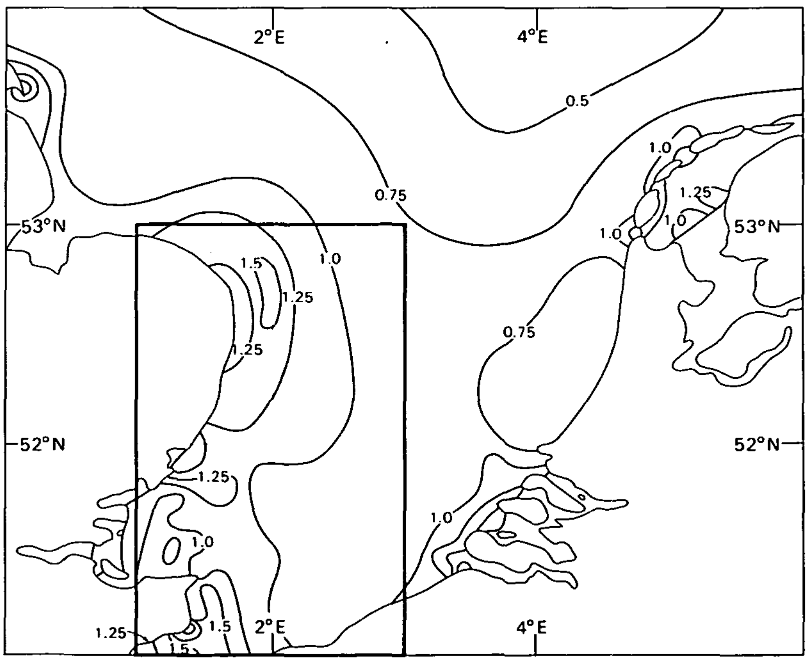

Figure 2 Contours of maximum speed of tidal streams, in metres $second^{-1}$ at mean spring tide (Adapted from Sager and Sammler, 1975). Heavy box denotes map area.

5. Bathymetry and seafloor topography

The Southern North Sea is a relatively shallow part of the UK continental shelf with water depths almost everywhere less than 50 m (see Map 5).

The most conspicuous topographic features are groups of elongate sandbanks. These can conveniently be divided into four main groups;

a) The Norfolk Banks

The Norfolk Banks are prominent features of the area to the north-east of Norfolk (Caston, 1972; Caston & Stride, 1970; Houbolt, 1968). These banks form a series of coast parallel features in an area extending from 10 to 90 km offshore. The largest of these within this sheet area is Haisborough Sand which is 21.5 km long, 2.2 km wide and 33.5 m high above the surrounding seafloor (Caston, 1972). Haisborough Sand forms part of a larger en echelon series showing a marked degree of asymmetry with a steeper slope to the north-east (c.5°) and a more gentle (c.1°) slope to the south-west (McCave and Langhorne, 1982).

Other coast parallel banks occur to the north-east of Great Yarmouth and between Southwold and the southern margin of the study area.

b) Thames Estuary Banks

This series of banks occupy much of the outer Thames Estuary area where they are forming due to longshore and landward transport of sediment into the estuary mouth.

The largest of these, Long Sand, is over 45 km long. Many of the banks dry at low water leaving only narrow navigable channels between them.

c) Offshore Southern North Sea Banks

A series of narrow elongate banks are found in the central part of the Southern North Sea where they form NNE-SSW trending ridges that are not coast-parallel unlike the previous two groups. These banks include North and South Falls, Inner and Outer Gabbard and the Galloper. Sediment movement in the vicinity of these banks was considered by Caston, (1981) and the relationship of the Galloper and another unnamed bank to the underlying geology by D'Olier (1981).

d) Nearshore banks

Banks forming at various places close to the eastern England coast include the Goodwin Sands off Kent (Cloet, 1954), and the Sizewell-Dunwich Banks off Suffolk (Lees, 1982; Robinson, 1980).

Summaries of the distribution, morphology and sediment dynamics of the Southern North Sea sandbanks can be found in Kenyon et al (1981) and Stride (1982).

Extensive areas of the sea bed are covered with large sandwaves. These sandwaves are probably the most extensively studied in the world. A good summary of this research can be found in Stride (1982). The sandwaves are up to 11 m in amplitude and have wavelengths between approximately 25 and 300 m. Occasional larger sandwaves are found mostly in the southern part of the area where tidal currents are strongest, the largest identified in the UK sector being 16 m in height. Large sandwaves also occur to the east in the Dutch sector (see McCave, 1971; Terwindt, 1971) who demonstrated a northward decrease in height for the Southern North Sea sandwaves. The sandwaves show complex patterns of migration, as implied by their direction of asymmetry on echo sounder records, particularly in the vicinity of the sandbanks. In the swales between the sandbanks the crests of the sandwaves are aligned approximately normal to the crestline, but on either side of the bank the sandwaves are deflected towards the crestline at angles of approximately 60° (steep face) and 50° (gentle face) (Caston, 1972). The crest of the bank itself may be devoid of sandwaves. At the ends of sandbanks a variety of directional trends may be seen (eg. Caston, 1981; McCave and Langhorne, 1982). Langhorne (1973) showed that, for a small area at the head of Long Sand, sandwaves, although mobile sea bed features, show little progressive movement from year to year although 'flexing' of sinuous crest lines may result in displacements of up to 25 m in a year. Other estimates of rate of movement and a summary of the general features of Southern North Sea sandwaves can be found in Eisma et al (1979).

Sandwaves are thought to form where:-

a) sufficient sand is available
b) currents are >0.6 ms^{-1} at mean spring tide
c) wave action is weak to moderate

Sandwaves are not generally found where there is an abundance of coarse sand or large amounts of fines.

The asymmetry of the sandwaves indicates the direction of movement of the bedform. This direction has been shown to correlate with the direction of maximum tidal current velocity and probably shows the direction of net sediment transport. This feature has therefore been used to map out the directions of regional sediment transport for the Southern North Sea (see Figure 3).

6. General distribution of sea bed sediments

The floor of this part of the southern North Sea is dominated by sands and gravelly sands. Muds are found in small local, mostly nearshore areas. These modern sediments are generally thin (less than 1 m) although accumulations may reach over 30 m in the shape of linear sandbanks which form coast parallel features around the East Anglian coast and within the outer part of the Thames Estuary. The thickness of the modern sediments reflects the very small input of sediment material into the Southern North Sea basin during the last 10,000 years.

In this report only the surface distribution of sediments is considered. Some data already exists within BGS regarding the thickness of modern sediments within the area (BGS 1984a, and in press) but further details of the variation of sediment type with depth are required before an accurate assessment of potential aggregate resources can be given.

(a) Surface distribution of coarse aggregate

Over much of the study area there is relatively little material (<5%) coarser than 5 mm within the surface sediments. In a few areas however the coarse aggregate content is much greater, over 80%. The most notable areas are:-

a) N of Cromer
b) E of Gt Yarmouth
c) SSE of Southwold
d) S and E of Orfordness
e) Large patches in the central Southern North Sea, E of the Thames Estuary
f) Dover Straits

From a comparison of Map 5 with Map 7 it can be seen that these areas of abundant coarse material correlate well with areas of existing gravel dredging licences, although environmental and operational problems prevent some of these gravelly areas being dredged.

From Map 5 it can be seen that there are only a few places where shell content is sufficiently high to downgrade the quality of the gravel. One such area is to the east of Aldeburgh. The high shell content here is probably a result of reworking of shelly Red Crag sediments rather than due to an input of modern shell material.

(b) Surface distribution of fine aggregate

Map 6 shows the distribution of sand grades categorised according to normal geological definitions (see map legend).

From the map it is clear that the majority of the sand sized sediment in the area is in the 'medium' (250-500 um) category. Patches of fine sand (125-250 um) often correlate with banks, with a general decrease in grain size from the interbank area towards the bank crest (see McCave and Langhorne, 1982). A large area of coarse sand (500-1000 um) correlates with bedload parting, in an area from where sediment is being transported, as indicated by Johnson et al (1982) (see Figure 3).

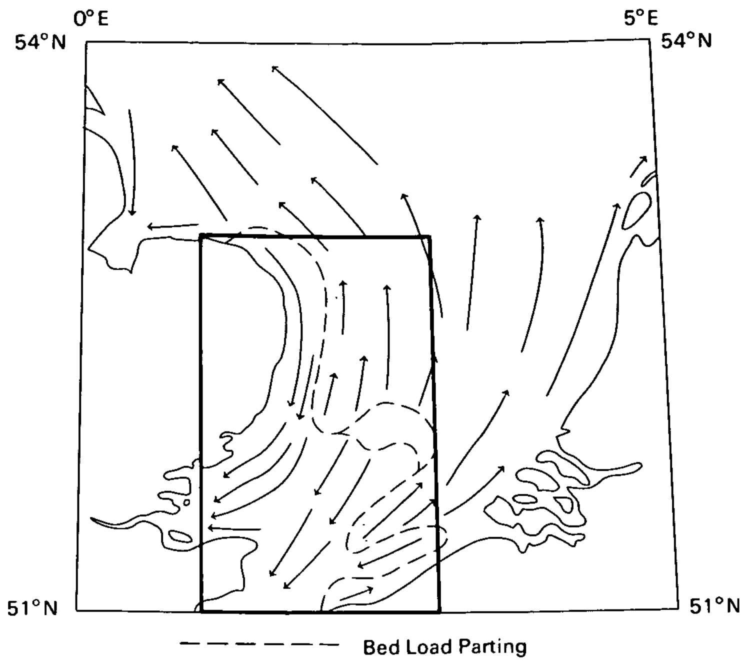

Figure 3 Net sand transport directions in the Southern North Sea (after Johnson et al, 1982).

7. General geology

Before discussing the sources of the sediments in the Southern North Sea it is necessary to briefly summarise the lithologies of the rocks which underlie and border this area. The distribution of these rocks is shown on Map 4. A simplified stratigraphy is shown in Figure 4.

Lower Cretaceous

The oldest rocks which directly underlie the study area are the Lower Cretaceous beds found in a small area in the extreme south, off Dover and Folkestone. These rocks comprise a mixture of mudstones, sandstones and conglomerates including flints, but due to their limited area of outcrop are relatively unimportant sediment contributors except in this localised area.

Chalk

The Chalk is found over a large area of seafloor off the east coast of Kent. The Chalk also borders much of the Tertiary sedimentary basin of which the Southern North Sea is part. The Chalk consists dominantly of cream to white or grey limestones with a variable hardness and clay content. The Upper Chalk contains abundant layers of flints which are an important constituent of marine aggregates.

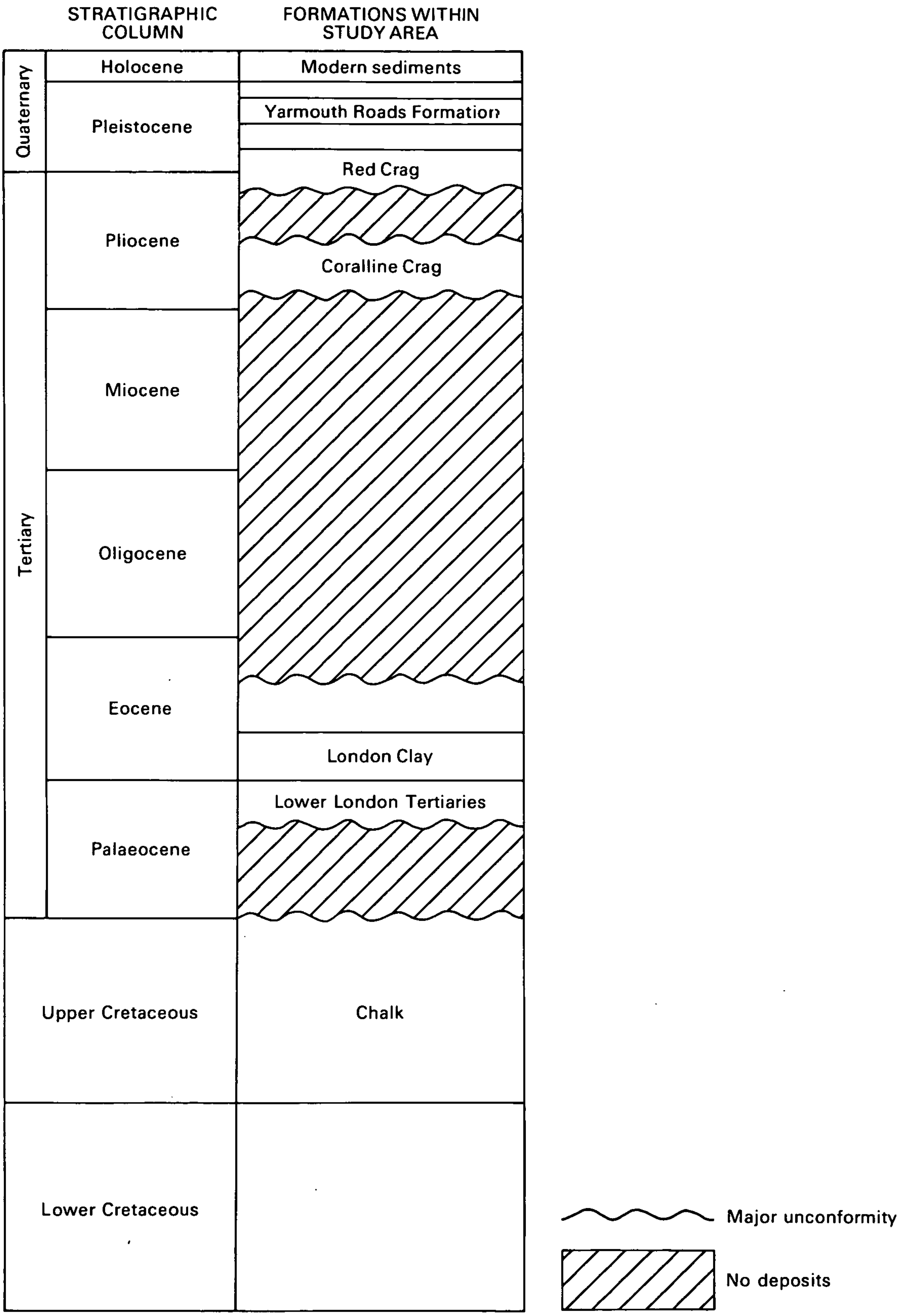

Figure 4 Simplified stratigraphy showing geological formation names used in this report.

The Lower Cretaceous and Chalk together probably contributed the majority of coarse flint material found within the study area. This may have been derived directly from erosion of the present day outcrops or indirectly from more recent deposits which themselves were formed by the erosion of these outcrops as for instance the flint gravels found in the Lower London Tertiaries and Quaternary deposits. Flint is a very resistant rock type and is capable of being reworked through several cycles of erosion and deposition.

Lower London Tertiaries (LLT)

The Lower London Tertiaries comprise a fairly thin sequence of sands, muddy sands and muds of Palaeocene age. There are occasional layers of well rounded flint pebbles derived from erosion of older rocks (see above).

The LLT outcrop is a thin band running eastwards from Kent and within a small area to the east of Harwich. Because of their limited outcrop they are unlikely to have been important contributors to the modern sediments.

London Clay and later Eocene formations

The London Clay outcrop covers almost one third of the study area. The London Clay consists of stiff muds with occasional layers of large carbonate septarian concretions (limestone) often up to 1 m in diameter and also layers of small phosphatic concretions up to 20 cm diameter. The London Clay is overlain to the east by later Eocene formations with similar lithologies.

Coralline Crag

The Coralline Crag is a Pliocene formation of shelly sands and limestones with a small outcrop in east Suffolk and extending a short distance offshore near Sizewell. Fragments of this limestone up to 30 or 40 cm diameter can be found on the seafloor in the immediate vicinity of the outcrop.

Red Crag and later Pleistocene formations

These formations cover over half of the seafloor in the study area. It is probable that they once covered an even larger area to the south but have been removed by erosion there.

The Red Crag and Pleistocene units have been mapped together for the purposes of this study. They represent a complex sequence of marine and non-marine deposits over 150 m thick in places within the study area. The sediments consist mostly of sands and shelly sands with some silts and clays.

Locally some of the units may be gravelly but information is as yet sparse. Gravel occurs within the Red Crag Formation. Gravel may also occur within the fluviatile formations such as the Yarmouth Roads

Formation which is probably the offshore equivalent in part of the Kesgrave Sands and Gravels which are currently worked onshore for aggregates.

The surface outcrop of the Yarmouth Roads Formation (see Balson and Cameron, 1985; BGS 1984b) to some extent correlates with areas of active gravel extraction to the east of Great Yarmouth.

Some Pleistocene units may include thin silt layers which after erosion of the enclosing sediment may yield siltstone pebbles into the sea bed deposits.

8. Sediment sources and transport

Only four sources of sediment need to be considered.

i) River input

The main river input into this area would be expected to be from the Thames in the west and to a lesser extent from the Rhine and Scheldt on the eastern margin. The amount of sediment being input by the Thames is known to be very small at the present time (c.200,000 tons year^{-1}, see Veenstra, 1971) and consists mostly of silt-sized material (see Prentice et al, 1968). The Rhine has a greater input (c.4 million tons year $^{-1}$) but much of this material is transported north along the Dutch coast (Veenstra, 1971).

ii) Coastal erosion

Coastal erosion is known to be an important source of sand-sized sediment particularly along the Norfolk coast.

iii) Marine transport from other offshore areas

Modern sediments are similarly thin in adjacent areas of the North Sea and eastern English Channel so transport of appreciable amounts of sediment into this area from these sources is unlikely.

iv) Reworking of older deposits on the seafloor

This is a very important source for the sea bed sediments of this area and is probably the only major source of coarse gravel material.

a) Gravel

The lithic gravel fraction in the study area is dominantly flint with some subordinate quartzite although other lithologies are common in certain areas. In areas underlain by Chalk rounded pebbles of this material may be common and may even be the dominant component of the modern sediment. The London Clay frequently yields fragments of septarian carbonate concretions which may be large (10-20 cm) and rare small phosphatic concretions of a few centimetres diameter. The Coralline Crag contributes large fragments and blocks of a porous limestone to the modern sediments but because of their size these are restricted to the immediate vicinity of the outcrop. At the base of the Red Crag is a conglomeratic band consisting of flint and phosphatic pebbles. This horizon was formerly worked onshore as a source of phosphates for fertiliser manufacture. Where Red Crag sediments offshore have been removed by erosion this conglomeratic material remains as a lag deposit intermingled with other modern sediment. Thus in the area immediately south of the Red Crag outcrop (see Map 4) abundant phosphatic pebbles (generally less than 10 cm diameter) may be encountered. These pebbles are generally hard although slightly less so than flint and only slightly calcareous and so should not prove detrimental to aggregate quality. These pebbles were originally reworked from the London Clay and other Tertiary deposits to become included within the basal Crag sediments. The later Pleistocene deposits are not generally known to be gravelly. Information is however sparse. The Yarmouth Roads Formation and other fluviatile units may bear gravel as indicated above, but this is as yet unproven. Gravel may also have originated from deposits now largely eroded and winnowed. Robinson (1968) interpreted gravel spreads off the Lincolnshire coast as glacial outwash fans left behind by the retreat of ice during the last ice age. This gravel however includes more exotic rock types than that of the study area (see Veenstra, 1969). The absence of underlying glacial deposits such as till within the study area indicates that this is probably not the origin for the gravels here. Veenstra (1969) believed that much of the Southern North Sea gravels derive from beach deposits built up from material of fluvial origin. Further work on petrology of the gravels may assist in determining their provenance.

Despite the high current velocities there is relatively little present day transport of gravel-sized material on the sea bed. This contrasts with the situation found on the East Anglian beaches and very close inshore where movement of pebbles does occur by the processes of longshore drift (Kidson, 1963; Kidson and Carr, 1959; Vincent, 1979).

b) <u>Sand</u>

An important source for the sand of this area are the Norfolk Cliffs between Weybourne and Happisburgh where erosion of Pleistocene sediments may provide about 400,000 m^3 of sand per year (see McCave, 1978). McCave (1978) also suggests that the headlands or nesses along the East Anglian coast are points where sand being transported along the coast by longshore drift converges and moves offshore into the bank systems (see also Carr, 1981; Robinson, 1966, 1980).

The best known of these headlands, Orford Ness, has been formed by longshore transport of flint gravel which has produced a shingle spit. In general, where the potential rate of longshore transport of sand exceeds the supply then gravel predominates in the beach sediment (Vincent, 1979).

Longshore transport is also responsible for the accumulation of sand within the Thames Estuary (D'Olier, 1974).

c) Mud

There is generally very little mud within the sediments of this area. Those areas with muddy sediment usually overlie earlier Holocene estuarine muds eg. in buried channels off Aldeburgh (Lees, 1982). Some muddy sediments further to the south overlie other large buried channels which were described by D'Olier (1972).

9. Dredging

The marine aggregate contribution to the UK construction industry is greatest in the south-east and offshore dredging for sand and gravel is extensive in areas off the Thames Estuary and Norfolk Coast (Map 7). The largest dredging ground is offshore from Great Yarmouth and Lowestoft whereas further south the licensed areas are generally smaller around Southwold, Shipwash, Kentish Knock, Sunkhead Towers, Long Sand and Gabbard.

The dredging industry has investigated most of the the sea bed in the study area in order to locate suitable reserves of sand and gravel within economical distance of the markets. The prospecting licences issued by the Crown Estate Commissioners have allowed the licencees to take samples from the sea bed using mainly grabs, dredges, vibrocorers and airlift corers. These methods provide information on the surface and near surface deposits but are restricted in their performance in underlying strata. Vibrocore penetration is limited by the presence of pebble and cobble sized material or in well-compacted sands, while the samples obtained by air-lift techniques are disturbed with lower strata significantly contaminated by material from above. Seismic methods for exploration of the sub-surface layers have not been widely used despite the availability of systems which can give penetration up to 20 m in gravel with resolution to ± 0.5 m. Side-scan sonar has been used in a few areas to give information on the nature of the bedforms and on the type of sediment on the sea bed.

If workable reserves of sand and gravel are indicated by the results of a prospecting survey it is then necessary to apply for an extraction licence. There are many potential objections to the issue of a dredging licence, but the most common relate to coastal erosion and fisheries. The science of coastal erosion is sophisticated and an assessment of coastal risk is beyond the scope of this report. Factors which affect coastal erosion in relation to dredging include water depth, tidal currents, bedforms, wind direction, storms and distance offshore. The major commercial species of fish potentially endangered by gravel dredging is the herring which spawns over certain gravel areas (Map 7), the eggs being attached to the gravel. Most of the known gravel areas on which herring spawn (MAFF, 1981) are situated well away from licensed dredging areas.

Other restrictions on dredging arise from the presence of telephone cables and pipelines on the sea bed which are protected by a corridor extending to 1 kilometre on each side.

10. Potential aggregate resources

The sea bed sediments of the Southern North Sea are dominated by sands and gravels with negligible amounts of mud. Sand is much more abundant than gravel but in some areas the sediment contains more than 80% gravel. The thickness of the deposits are not known in detail but they are likely to be less than 1 m thick over most of the area.

Maps 5 and 6 show the surface distribution of both fine and coarse aggregate as interpreted from available data. This distribution (see page 8) illustrates the close correlation between licensed dredging areas and areas where the sediment contains abundant gravel. More information is required to determine the exact location and thickness of aggregate resources in the area.

11. Recommendations for geophysical and sampling survey

Although the surface distribution of sea bed sediments in this area is relatively well known, little is known about the thickness of the gravel-bearing deposits and there is a lack of the geological information required for satisfactory resource appraisal.

In order to provide the framework for resource appraisal it would be necessary to undertake a geophysical survey to determine the seismo-stratigraphy of the area and to follow this with a sampling survey to calibrate the geophysical results.

The geophysical survey should deploy the following equipment:-

a) Boomer, pinger and sparker seismic systems to produce high quality continuous reflection profiles
b) A sidescan sonar system to produce an acoustic picture of the sea bed
c) An echo sounder system to provide bathymetric data
d) A navigation system (Decca Main Chain)

The sampling equipment used would be governed by cost and the difficulty of coring in coarse sediment. However it is recommended that a large grab should be used to take surface samples and a vibrocore system should be used to obtain material from bored holes.

The Department of the Environment are commissioning BGS to survey an area off the East Anglian coast in 1986/87. The area to be surveyed extends for some 70 km from north to south off the coast between Winterton to Aldeburgh and from a minimum water depth of 20 metres (approximately 10 fathoms) to a distance of around 40 km offshore (Figure 5). It is recommended that about 1250 km of geophysical traverse will be required to adequately survey this area. This is based on a regular 5 km x 5 km grid across the survey area totalling approximately 1000 km, with an additional 250 km of geophysical traverse over areas of likely sand and gravel resources identified during the on-board interpretation of the results. A minimum of 40 vibrocore holes will be necessary to provide material to calibrate the geophysical results.

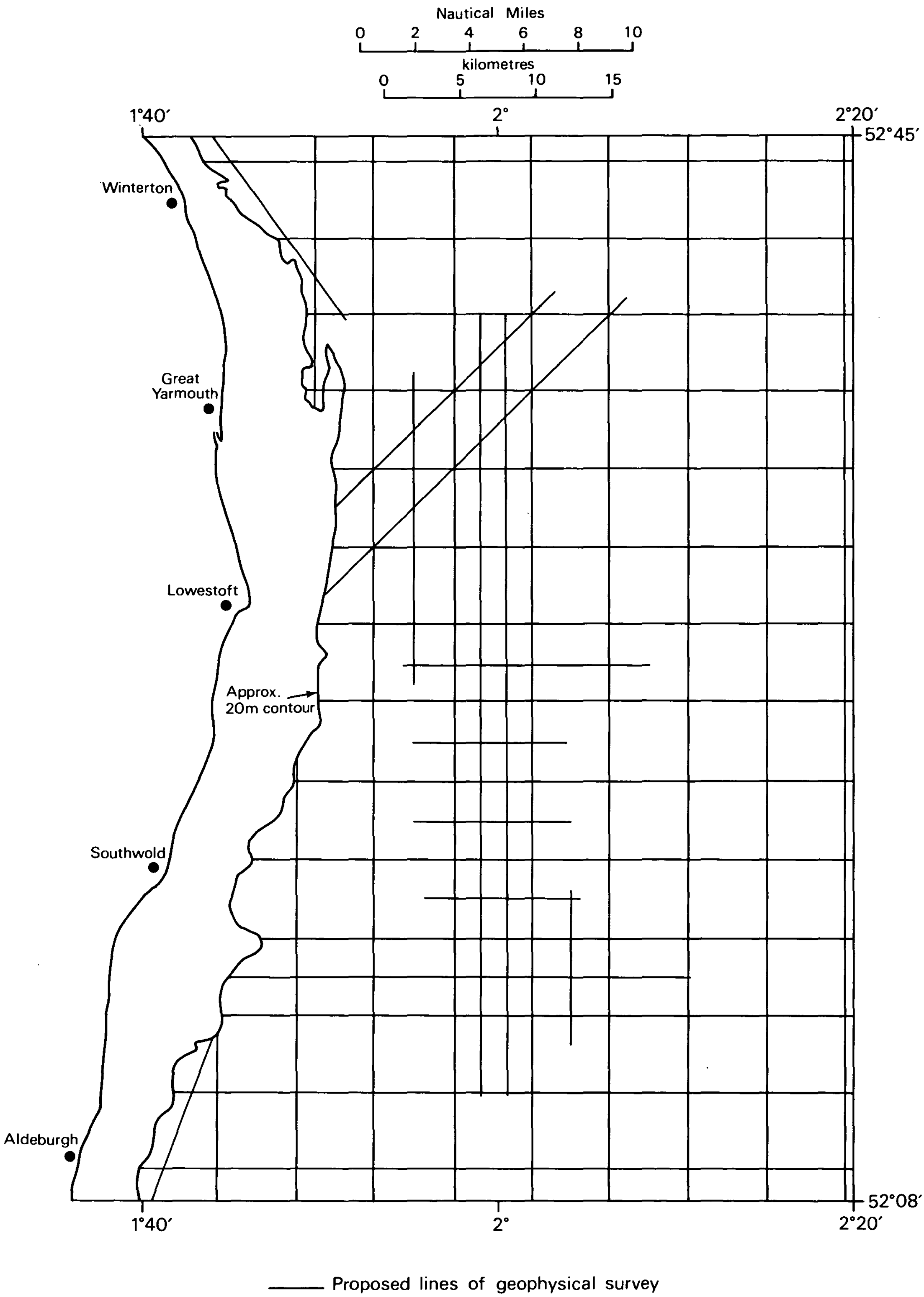

Figure 5. Proposed Survey Area

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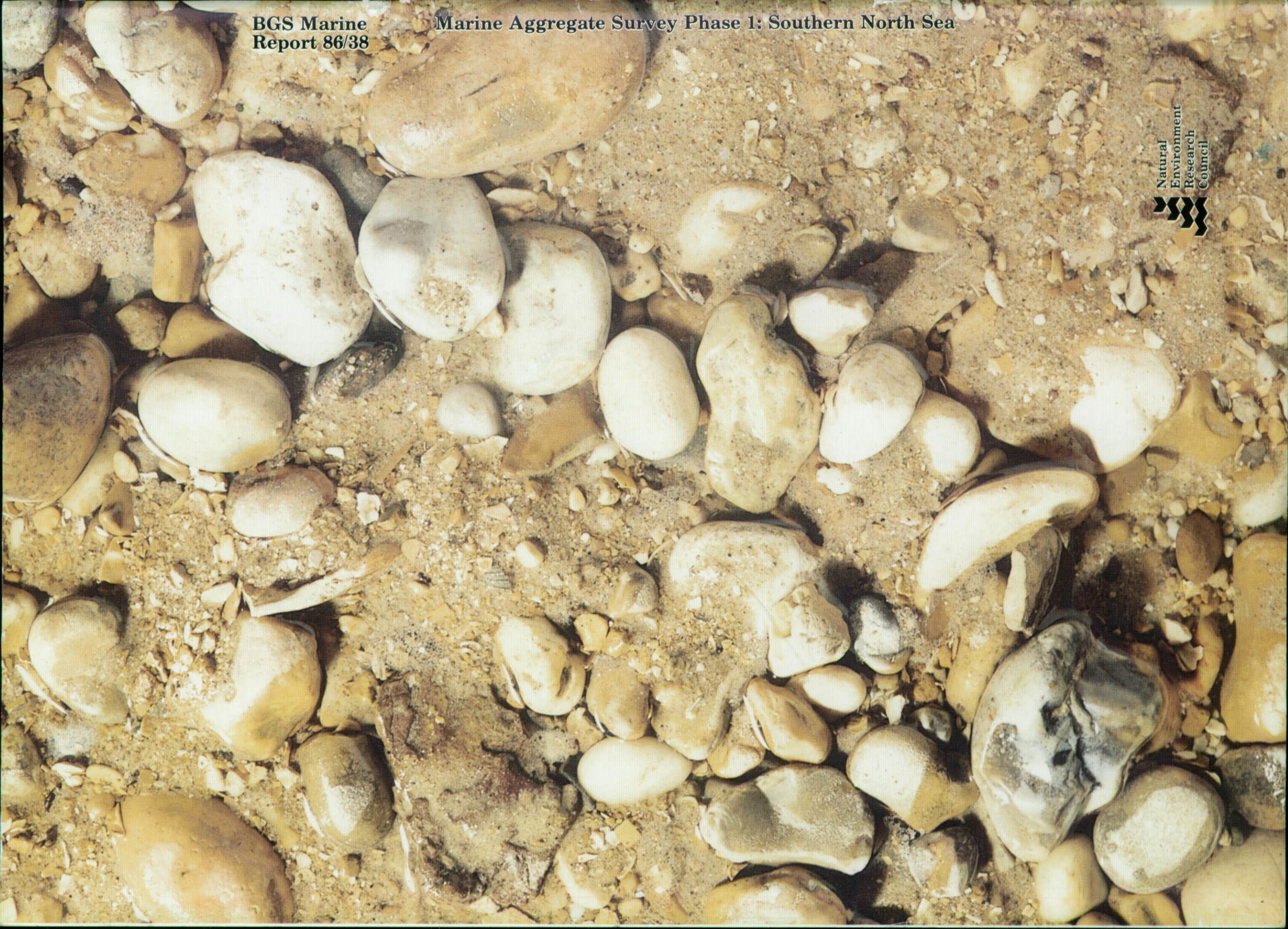
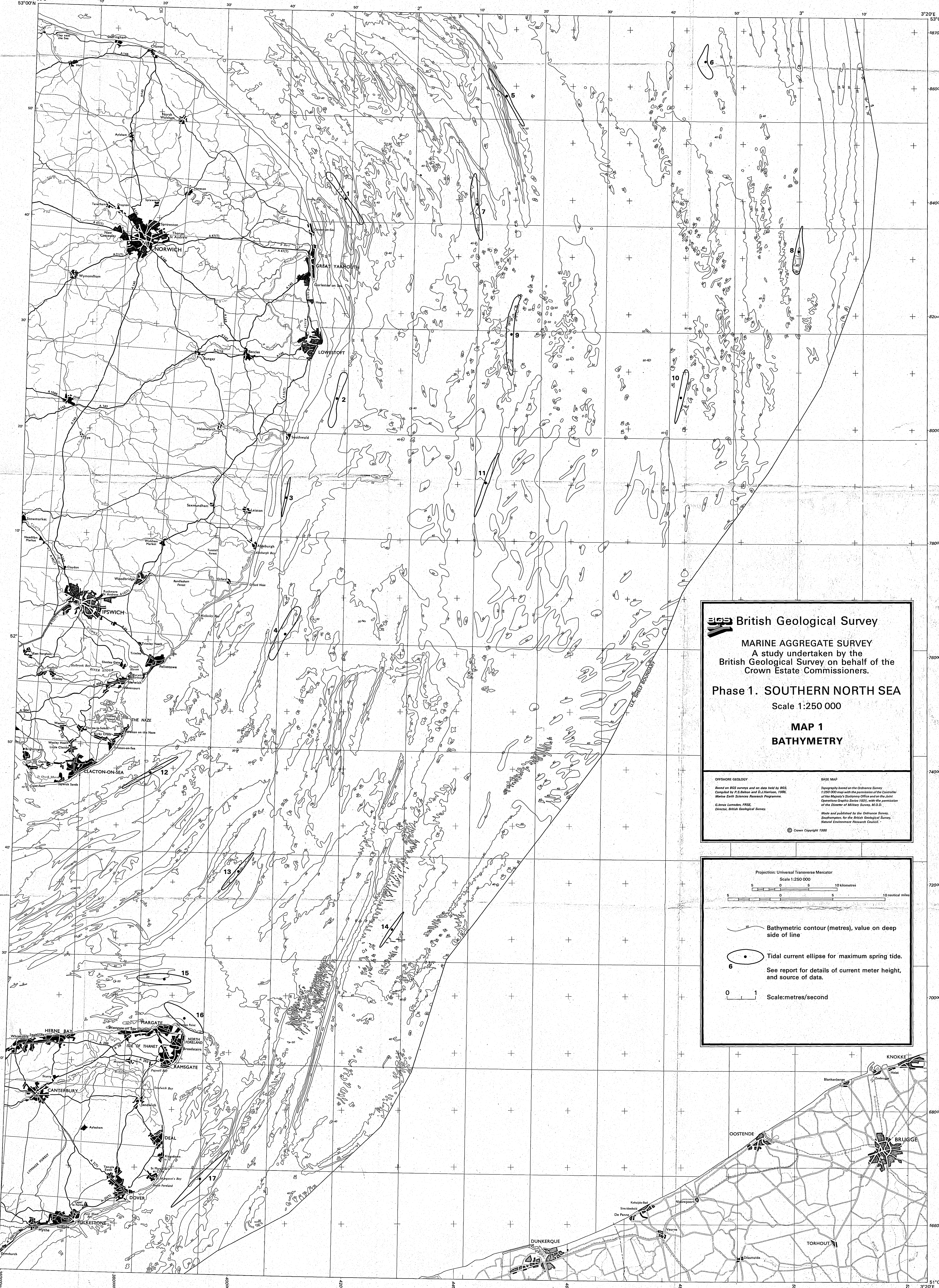
Appendix

Details of tidal current data used on Map 1

Current meter station	Height of meter above seabed (m)	Duration of recording (days)	Source
1	7	8	MAFF
2	6	57	MAFF
3	6	68	IOS
4	7	29	MAFF
5	sea surface	-	HD
6	"	-	HD
7	"	-	HD
8	"	-	HD
9	"	-	HD
10	"	-	HD
11	"	-	HD
12	4	29	MAFF
13	10	56	MAFF
14	8	70	MAFF
15	5	55	MAFF
16	4	55	MAFF
17	5	46	IOS

MAFF	=	Ministry of Agriculture, Fisheries and Food
IOS	=	Institute of Oceanographic Sciences
HD	=	Hydrographic Dept. (MOD) from published Admiralty charts


BGS Marine
Report 86/38
Marine Aggregate Survey Phase 1: Southern North Sea
Natural
Environment
Research
Council



British Geological Survey
MARINE AGGREGATE SURVEY
A study undertaken by the British Geological Survey on behalf of the Crown Estate Commissioners.
Phase 1. SOUTHERN NORTH SEA
Scale 1:250 000
MAP 1
BATHYMETRY
OFFSHORE GEOLOGY
Based on BGS surveys and on data held by BGS. Compiled by P.S.Balson and D.J.Harrison, 1986, Marine Earth Sciences Research Programme.
G.Innes Lumsden, FRSE, Director, British Geological Survey.
BASE MAP
Topography based on the Ordnance Survey 1:250 000 map with the permission of the Controller of Her Majesty's Stationery Office and on the Joint Operations Graphic Series 1501, with the permission of the Director of Military Survey, M.O.D.
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Projection: Universal Transverse Mercator
Scale 1:250 000
10 kilometres
10 nautical miles
Bathymetric contour (metres), value on deep side of line
Tidal current ellipse for maximum spring tide.
See report for details of current meter height, and source of data.
Scale:metres/second
U.K. SHELF BOUNDARY
NORWICH
GREAT YARMOUTH
LOWESTOFT
Southwold
Aldeburgh
IPSWICH
Felixstowe
Harwich
THE NAZE
CLACTON-ON-SEA
HERNE BAY
MARGATE
NORTH FORELAND
RAMSGATE
CANTERBURY
DEAL
DOVER
FOLKESTONE
KNOKKE
Blankenberge
Zeebrugge
OOSTENDE
BRUGGE
DUNKERQUE
TORHOUT
53°00'N
51°00'N
1°00'E
3°20'E

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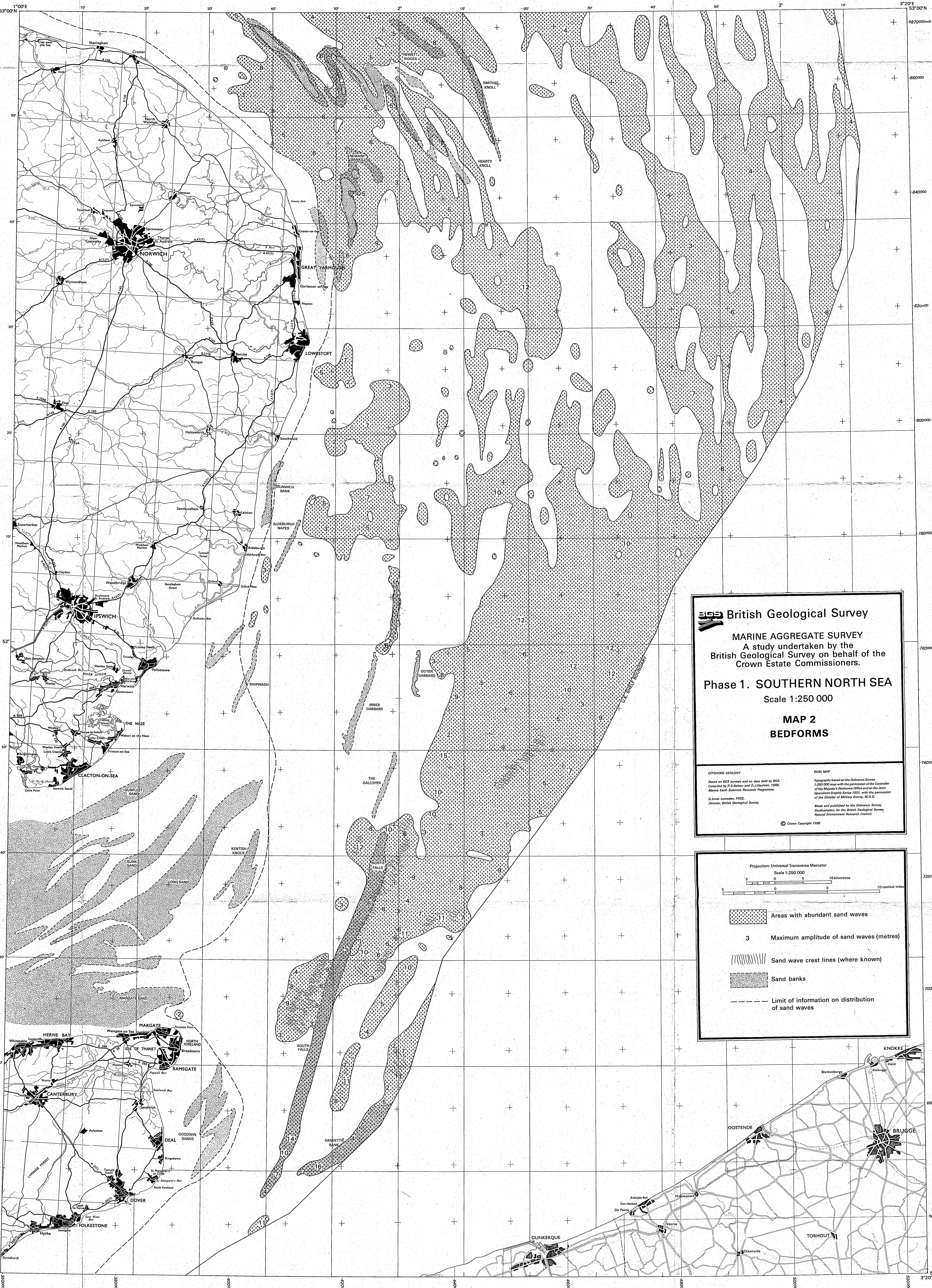
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A study undertaken by the
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Crown Estate Commissioners.
Phase 1. SOUTHERN NORTH SEA
Scale 1:250 000
MAP 2
BEDFORMS
OFFSHORE GEOLOGY
Based on BGS surveys and on data held by BGS. Compiled by P.S.Balson and D.J.Harrison, 1986. Marine Earth Sciences Research Programme.
G.Innes Lumsden, FRSE, Director, British Geological Survey.
BASE MAP
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Projection: Universal Transverse Mercator
Scale 1:250 000
10 kilometres
10 nautical miles
Areas with abundant sand waves
3 Maximum amplitude of sand waves (metres)
Sand wave crest lines (where known)
Sand banks
Limit of information on distribution of sand waves
U.K. SHELF BOUNDARY
HEWETT RIDGES
SMITHS KNOLL
HEARTY KNOLL
NEWARP BANKS
DUNWICH BANK
ALDEBURGH NAPES
SHIPWASH
OUTER GABBARD
INNER GABBARD
THE GALLOPER
KENTISH KNOCK
NORTH FALLS
SOUTH FALLS
SANDETTIE BANK
GOODWIN SANDS
GUNFLEET SAND
SUNK SAND
LONG SAND
MARGATE SAND
NORWICH
GREAT YARMOUTH
LOWESTOFT
IPSWICH
CLACTON-ON-SEA
HERNE BAY
MARGATE
RAMSGATE
CANTERBURY
DEAL
DOVER
FOLKESTONE
KNOKKE
BRUGGE
OOSTENDE
TORHOUT
DUNKERQUE
53°00'N
51°00'N
1°00'E
3°20'E

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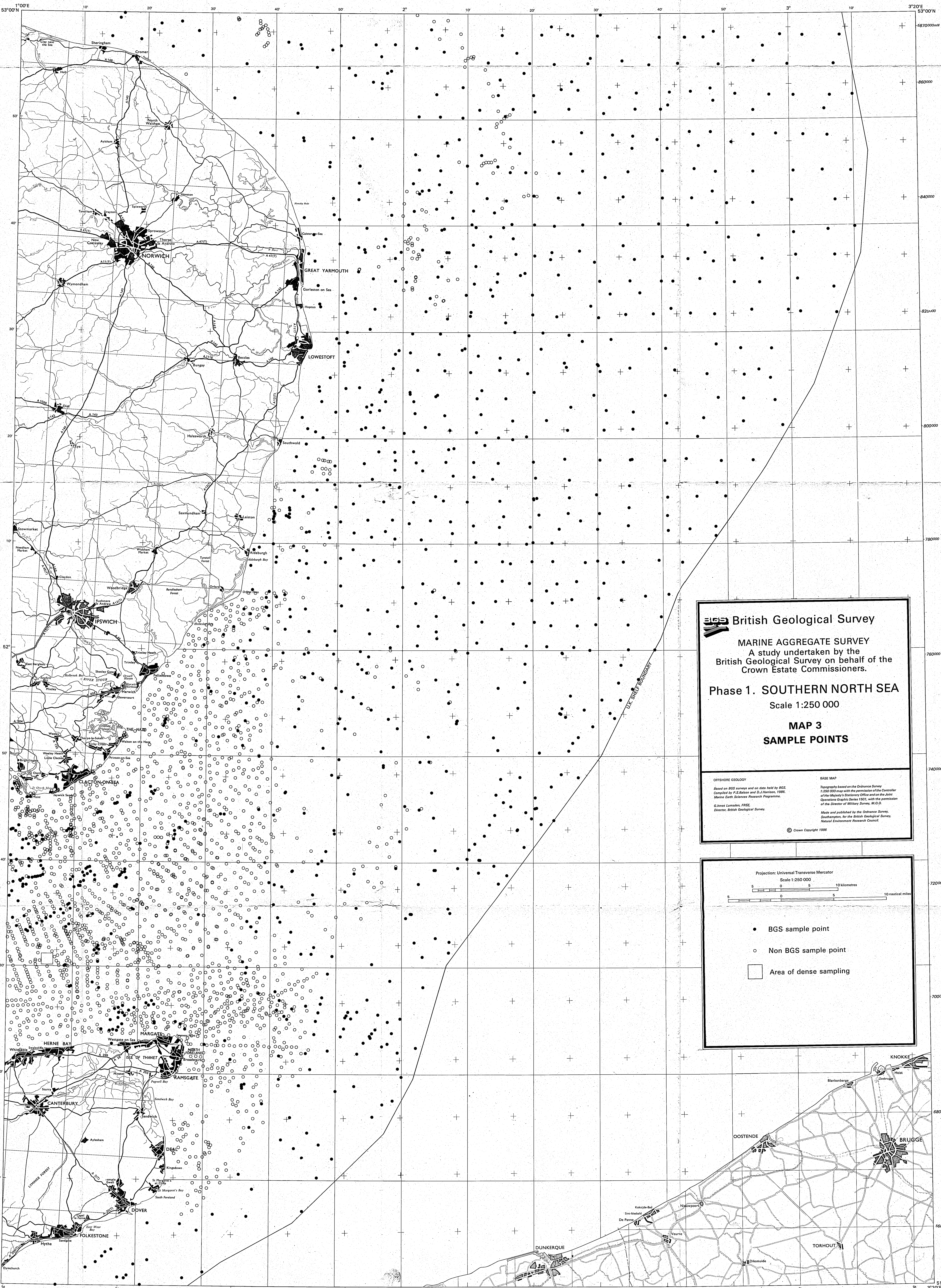
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A study undertaken by the
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Phase 1. SOUTHERN NORTH SEA
Scale 1:250 000
MAP 3
SAMPLE POINTS
OFFSHORE GEOLOGY
Based on BGS surveys and on data held by BGS.
Compiled by P.S.Balson and D.J.Harrison, 1986,
Marine Earth Sciences Research Programme.
G.Innes Lumsden, FRSE,
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Projection: Universal Transverse Mercator
Scale 1:250 000
10 kilometres
10 nautical miles
BGS sample point
Non BGS sample point
Area of dense sampling
U.K. SHELF BOUNDARY
1°00'E
2°
3°
3°20'E
53°00'N
52°
51°00'N
NORWICH
GREAT YARMOUTH
LOWESTOFT
IPSWICH
CLACTON-ON-SEA
HERNE BAY
MARGATE
RAMSGATE
CANTERBURY
DOVER
FOLKESTONE
DUNKERQUE
OOSTENDE
BRUGGE
KNOKKE

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Phase 1. SOUTHERN NORTH SEA
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MAP 4
SEA BED SEDIMENTS AND UNDERLYING GEOLOGY
OFFSHORE GEOLOGY
Based on BGS surveys and on data held by BGS. Compiled by P.S.Balson and D.J.Harrison, 1986. Marine Earth Sciences Research Programme.
G.Innes Lumsden, FRSE, Director, British Geological Survey.
BASE MAP
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Projection: Universal Transverse Mercator
Scale 1:250 000
5 0 5 10 kilometres
5 0 5 10 nautical miles
SEA BED SEDIMENTS
M .... Mud
sM .... Sandy mud
gM .... Gravelly mud
S .... Sand
mS .... Muddy sand
gmS .... Gravelly muddy sand
gS .... Gravelly sand
G .... Gravel
mG .... Muddy gravel
msG .... Muddy sandy gravel
sG .... Sandy gravel
Sediment boundary
Limit of sediment data
GEOLOGY
Red Crag and later deposits (Quaternary)
Coralline Crag (CC)
London Clay (LC)
Lower London Tertiaries (LLT)
Chalk
Lower Cretaceous
Geological boundary
U.K. SHELF BOUNDARY
NORWICH
GREAT YARMOUTH
LOWESTOFT
IPSWICH
CLACTON ON SEA
HERNE BAY
MARGATE
RAMSGATE
CANTERBURY
DEAL
DOVER
FOLKESTONE
DUNKERQUE
OOSTENDE
BRUGGE
KNOKKE
TORHOUT

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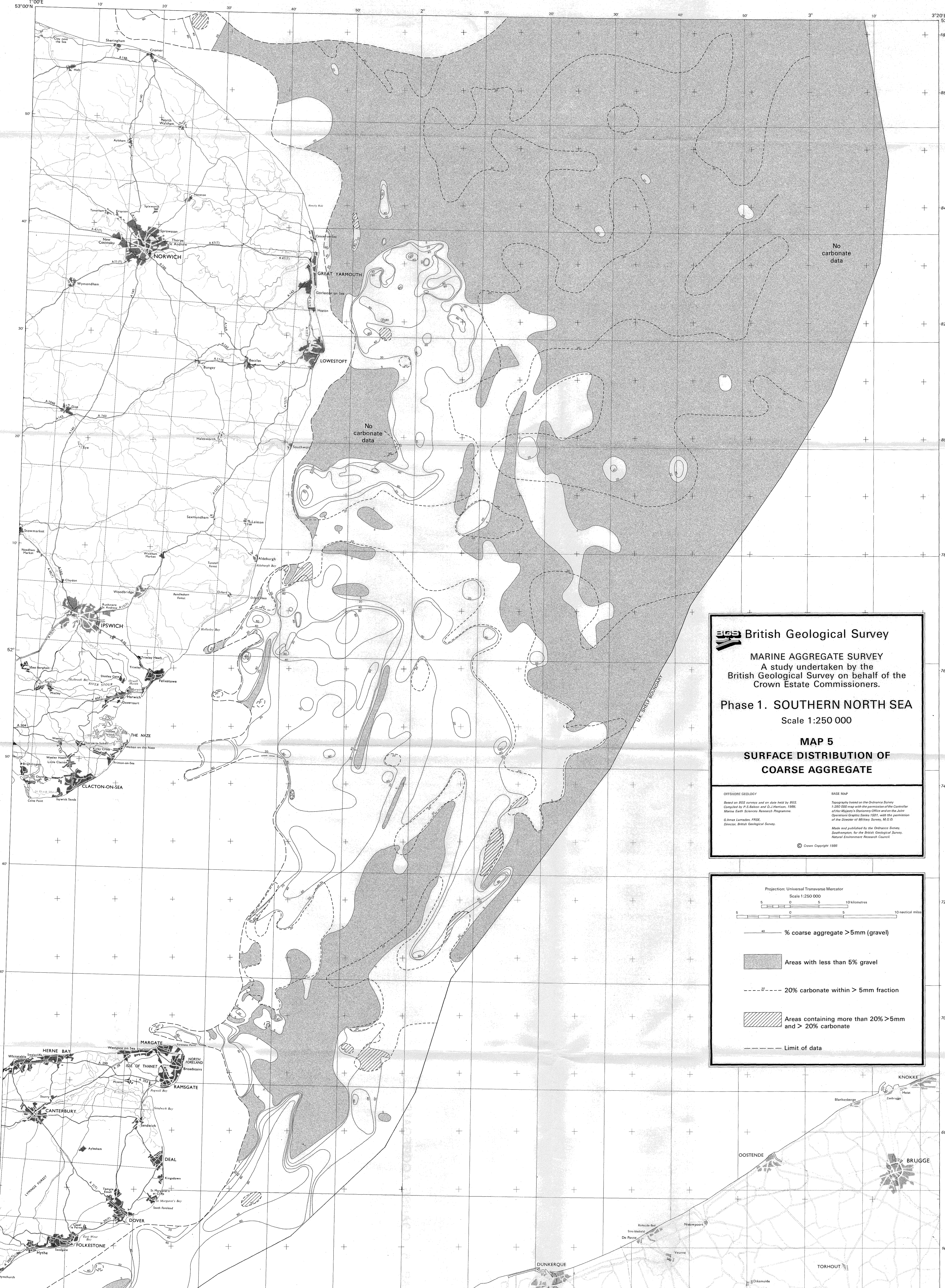

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MARINE AGGREGATE SURVEY
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Phase 1. SOUTHERN NORTH SEA
Scale 1:250 000
MAP 5
SURFACE DISTRIBUTION OF COARSE AGGREGATE
OFFSHORE GEOLOGY
Based on BGS surveys and on data held by BGS. Compiled by P.S.Balson and D.J.Harrison, 1986, Marine Earth Sciences Research Programme.
G.Innes Lumsden, FRSE, Director, British Geological Survey.
BASE MAP
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Projection: Universal Transverse Mercator
Scale 1:250 000
5 0 5 10 kilometres
5 0 5 10 nautical miles
% coarse aggregate >5mm (gravel)
Areas with less than 5% gravel
20% carbonate within > 5mm fraction
Areas containing more than 20% >5mm and > 20% carbonate
Limit of data
No carbonate data
No carbonate data
U.K. SHELF BOUNDARY
Sheringham
Cromer
North Walsham
NORWICH
GREAT YARMOUTH
Gorleston on Sea
LOWESTOFT
Beccles
Bungay
Diss
Eye
Halesworth
Southwold
Saxmundham
Leiston
Aldeburgh
Stowmarket
Wickham Market
Woodbridge
Orford
IPSWICH
Felixstowe
Harwich
Dovercourt
THE NAZE
Walton on the Naze
CLACTON-ON-SEA
HERNE BAY
Whitstable
MARGATE
NORTH FORELAND
Broadstairs
ISLE OF THANET
RAMSGATE
CANTERBURY
Sandwich
DEAL
Kingsdown
DOVER
FOLKESTONE
Hythe
KNOKKE
Heist
Zeebrugge
Blankenberge
OOSTENDE
BRUGGE
Nieuwpoort
De Panne
Veurne
DUNKERQUE
TORHOUT
Diksmuide
53°00'N
51°00'N
1°00'E
3°20'E

WBIMR/86/38

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Phase 1. SOUTHERN NORTH SEA
Scale 1:250 000
MAP 6
SURFACE DISTRIBUTION OF FINE AGGREGATE (SAND)
OFFSHORE GEOLOGY
Based on BGS surveys and on data held by BGS. Compiled by P.S.Balson and D.J.Harrison, 1986, Marine Earth Sciences Research Programme.
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BASE MAP
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Projection: Universal Transverse Mercator
Scale 1:250 000
10 kilometres
10 nautical miles
Mean Grain Size of Sand Fraction
phi mm.
-1 2
VC Very coarse
0 1
C Coarse
1 0.5
M Medium
2 0.25
F Fine
3 0.125
VF Very fine
4 0.0625
Limit of data
U.K. SHELF BOUNDARY
NORWICH
GREAT YARMOUTH
LOWESTOFT
IPSWICH
CLACTON-ON-SEA
HERNE BAY
MARGATE
RAMSGATE
CANTERBURY
DEAL
DOVER
FOLKESTONE
DUNKERQUE
OOSTENDE
BRUGGE
KNOKKE
TORHOUT
53°00'N
51°00'N
1°00'E
3°20'E

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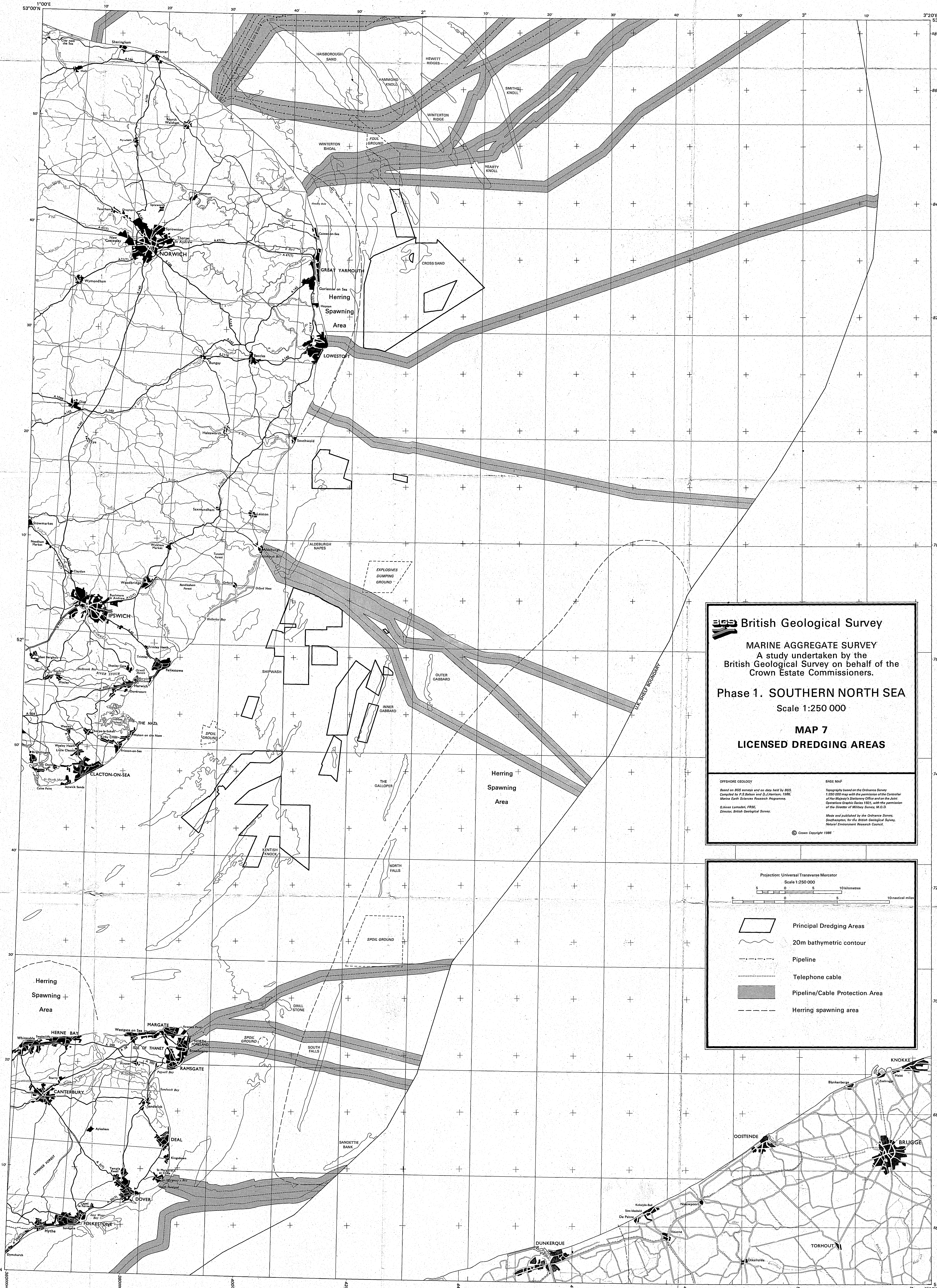
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Phase 1. SOUTHERN NORTH SEA
Scale 1:250 000
MAP 7
LICENSED DREDGING AREAS
OFFSHORE GEOLOGY
Based on BGS surveys and on data held by BGS. Compiled by P.S.Balson and D.J.Harrison, 1986, Marine Earth Sciences Research Programme.
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Projection: Universal Transverse Mercator
Scale 1:250 000
10 kilometres
10 nautical miles
Principal Dredging Areas
20m bathymetric contour
Pipeline
Telephone cable
Pipeline/Cable Protection Area
Herring spawning area
53°00'N
1°00'E
3°20'E
51°00'N
HAISBOROUGH SAND
HEWETT RIDGES
HAMMOND KNOLL
SMITHS KNOLL
WINTERTON RIDGE
WINTERTON SHOAL
FOUL GROUND
HEARTY KNOLL
CROSS SAND
Sheringham
Cromer
North Walsham
NORWICH
Wymondham
GREAT YARMOUTH
Herring Spawning Area
LOWESTOFT
Southwold
Halesworth
Saxmundham
Leiston
Aldeburgh
ALDEBURGH NAPES
EXPLOSIVES DUMPING GROUND
Woodbridge
IPSWICH
Felixstowe
Harwich
SHIPWASH
OUTER GABBARD
INNER GABBARD
U.K. SHELF BOUNDARY
THE NAZE
SPOIL GROUND
CLACTON-ON-SEA
THE GALLOPER
KENTISH KNOCK
NORTH FALLS
SPOIL GROUND
DRILL STONE
MARGATE
HERNE BAY
ISLE OF THANET
RAMSGATE
SOUTH FALLS
CANTERBURY
DEAL
SANDETTIE BANK
DOVER
FOLKESTONE
Hythe
KNOKKE
Blankenberge
Zeebrugge
OOSTENDE
BRUGGE
Nieuwpoort
De Panne
Veurne
DUNKERQUE
Diksmuide
TORHOUT

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