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DTI strategic Environmental Assessment Area 2 (SEA2) geological processes (interpretation of multibeam, sidescan sonar, chirp and grain size data acquired in 2001 from the seafloor on the Norfolk Banks and Dogger Bank, southern North Sea)

Continental Shelf and Margins Programme

Commissioned Report CR/03/188

BRITISH GEOLOGICAL SURVEY

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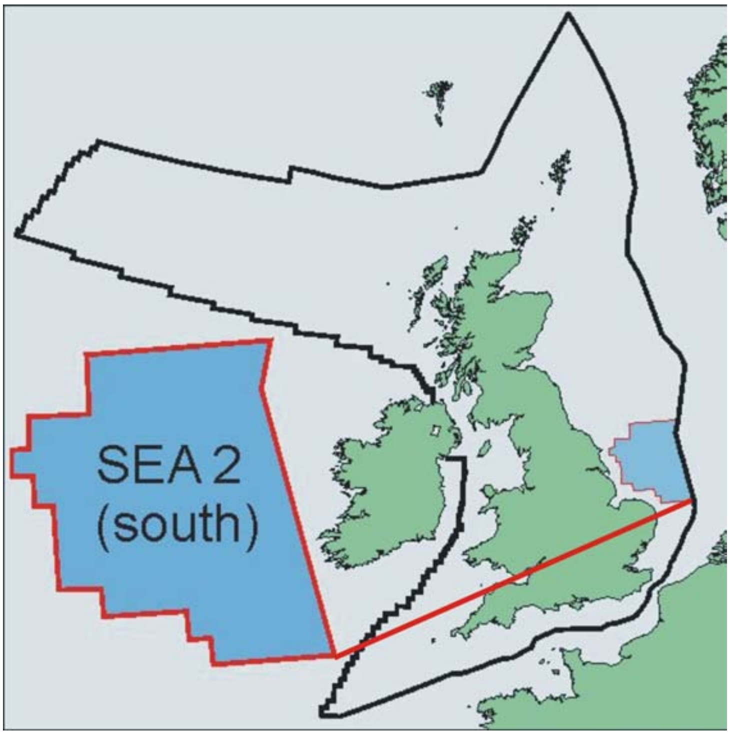
R Holmes & J B L Wild

Key words

Southern North Sea, geology, sandbanks, seismic reflection surveys, seabed.

Front cover

Scope of research



Bibliographical reference

HOLMES, R. & WILD, J.B.L. 2003. DTI Strategic Environmental Assessment Area 2 (SEA2) geological processes: (interpretation of multibeam, sidescan sonar, chirp and grain size data acquired in 2001 from the seafloor on the Norfolk Banks and Dogger Bank, southern North Sea) *British Geological Survey Internal Report*, CR/03/188. pp.

Edinburgh British Geological Survey 2003

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FORWARD

This report is the product of a desk study by the British Geological Survey (BGS) in response to a contract from Geotek Ltd to report on the interpretation of the geological aspects of sand bank processes and function in the Department of Trade and Industry Strategic Environmental Assessment area 2 (SEA2) in the southern North Sea. The report links a review of pre-existing research with the results of interpretations from new sidescan sonar, swath bathymetry, chirp profile, photographic and particle size data collected by the Department of Trade and Industry in 2001 and 2002. One importance of the research area is that it includes large area of seabed that is environmentally sensitive to commercial developments of natural gas fields. These contain the major part of the gas reserves on the UK continental shelf. The area of study encloses world-class sand banks and sand ridges that play an important part in sustaining the natural biodiversity of the SEA2 and more generally of the southern North Sea.

ACKNOWLEDGEMENTS

Funding for this programme of research was managed by Geotek Ltd in partnership with Hartley Anderson Ltd and funded by the Department of Trade and Industry.

The responsibilties for the production of this report have been as follows:

R Holmes- SEA2 south: review of pre-existing data, interpretation of new data
B Wild- SEA2 south: compilation of existing and new data into GIS
G Tulloch-SEA2 south: grain size analysis, organisation of photographic and grain size data for GIS
R Holmes, P Balson, H Johnson, S Jones, M Lewis, R M W Musson, R Parnaby - north and south SEA2 syntheses of regional geology , North Sea

Summary

The focus of this study is on the offshore sandbanks occurring in the mature southern North Sea gas producing fields on the UK continental shelf. New geological interpretations have been made from bathymetric, sidescan sonar and seabed photographic and sample surveys carried out for the Department of Trade and Industry in 2001 over the Norfolk Banks and the Dogger Bank. The survey data were acquired in water depths varying from approximately 10m to 40m or more. The new survey data were collected to fill information gaps on the seabed processes influencing the seabed sand transport directions, composition of the seabed habitat and sandbank function. Interpretative data have been collected for bedforms ranging in size from sand banks more than 20km long and spaced more than 5km apart to sand ripples less than 2m long and spaced less than 60cm apart. Existing geological information has been integrated with the new survey information to present the interpretations of the variety of the modern seabed habitats in their wider historical and regional contexts. The research findings from the seabed study are interpreted from data collected during relatively calm spring/summer wave conditions and without surge-driven tides.

- Under the range of seasonal hydrodynamic conditions the sandbanks interact with the flood and ebb tidal currents, wind and wave and storm surge currents so that the seabed on the sandbanks is characterised by superimposed mobile small to very large mobile bedforms. The exceptions found were on and adjacent to the crest of the Dogger Bank and on the crests of the Norfolk Banks all in less than approximately 18m water depth. In these areas the larger transverse bedforms appear to have been destroyed at the bank crests by waves.

- The Dogger Bank is a glacial outwash feature that was deposited under conditions of prolific sediment supply when the southern North Sea basin was partly covered by a terrestrial ice sheet more than 14,000 years ago. Although it is now covered by mobile sand at seabed, the bulk of the Dogger Bank in the area of survey is immobile and consists of cohesive muddy and gravelly sediments that are resistant to erosion.

- The main changes of seabed mean grain size across the Dogger Bank at the West Patch occur in areas with patchy seabed hollows with an origin from to scour caused by strong near-bottom currents during storms. The seabed sediments occurring outside the scours are predominantly well sorted fine sands. The seabed sediments in the scours are characterised by relict very poorly sorted muddy and gravely sands.

- The Norfolk Banks formed following the retreat of the terrestrial ice sheet, marine inundation of the southern North Sea and by interactions between sea-level changes, prolific sediment supply and near-bottom currents. The bulk volumes of the banks consist of predominantly uncohesive submarine sands that are not resistant to erosion by strong currents.

- Internal data from the Broken Bank have been interpreted to propose a possible a generic model for the historical development and integral function of the active banks in the region. The model is important to understanding the long-stability of the banks because it indicates that the oldest banks may be segmented into aggrading (heads) and younger prograding tails (NW ends) that are sensitive to changes in position of the heads. On the basis of their internal structure and external geomorphology both the banks heads and tails have migrated to the NE. There is no data for an understanding of the nature of the along-bank transition from aggrading to prograding internal structure.

- There is an overall positive correlation between the transverse bedform facing directions and the trends of decreasing mean grain size in the medium to fine sand fraction of the seabed sediments on the Norfolk Banks. The correlation is interpreted to infer net sand bedload transport directions across and between the banks to the north and east.

- The trends of mean sand grain size with position on Ower Bank B appear to show the existence of segments of decreasing mean grain size to the NE across the bank and decreasing mean grain size along the bank flanks in a clockwise direction. These trends are interpreted to confirm what has been previously inferred for nearshore banks but not calibrated by regional sampling, namely that both across- and along-bank sediment transport processes interact to influence bank seabed composition.

- On the basis of the interpretation of the data from Ower Bank B and the consistency of single profiles across other banks a process model is proposed that may be applied to predict segmented systematic variations in the composition and functions of the active banks. The model predicts that the finest seabed sediments within the sand fraction will be observed on the SE flank of the segment under the influence of the process identified.

- There is an overall decrease of mean grain size with decreasing water depth on the banks in the region that are outside the influence of the strongest tidal currents.

- The interpretations of the new regional seabed sediment textural data have confirmed the uniqueness of the functions of the Norfolk Bank relative to surrounding banks.

Contents

1. Introduction

1.1 Legal framework and scope of work

The Department of Trade and Industry Offshore Environment and Decommissioning, Licensing and Consents Unit (hereafter DTI) is responsible to the UK government for administering legal environmental legislation applicable to the oil and gas industry offshore. One such piece of legislation is an EC Directive (2001/42/EEC). The Directive is generic and wide ranging 'on the assessment of the effects and certain plans and programs on the environment.' The activities regulated cover seismic surveys, drilling, seabed development operations and decommissioning of offshore development structures. Although the Directive will be first converted into regulations by 21 July 2004, the UK has anticipated its requirements of the directive requiring the carrying out of Strategic Environmental Assessments (SEAs) prior to new oil and gas industry licensing rounds. To meet this requirement a program of habitat research on existing data and acquisition of new ship-borne data was initiated in 2001 by the DTI for selected areas within the DTI Strategic Environmental Assessment 2 area (SEA2) in the North Sea (Figures 1, 2). The DTI SEA research is also supportive of the legal legislation arising from EU Habitats Directive (92/43/EEC) on the conservation of natural habitats and of wild flora and fauna and the Bird's Directive (79/409/EEC) on the conservation of wild birds. These Directives state that improvement of scientific and technical knowledge is essential for their informed implementation. The (92/43/EEC) EU Habitats Directive's fundamental purpose is to establish a network of protected (Natura 2000) sites through the Community territory. Economic developments within these sites are not ruled out but it is intended that developments can proceed in a way where healthy natural habitats can be sustained. The aim of this report is to contribute to the range of geological technical knowledge and scientific interpretation that can be used for the informed implementation of the EU Directives.

SEA2 has been divided by the DTI into the southern SEA2, the major UK natural gas resource province and the northern SEA2, a major UK oil, condensate and natural gas resource province (Figures 1, 2). Although the SEA2 occurs offshore from the 12 nautical mile boundary, the area of SEA2 is legally governed by the Directives because it is within the 200 nm exclusive zone claimed by the UK. There are three major habitats as defined by the EU in the SEA2. These are defined in the Annex 1 of the Habitats Directive (92/43/EEC) and in the Interpretation Manual of European Union Habitats (EUR 15/2):

'reefs' (Natura 2000 Code 1170): 'Submarine, or exposed at low tide, rocky substrates and biogenic concretions, which arise from the seafloor in the sublittoral zone but may extend to the littoral zone where there is an uninterrupted zonation of plant and animal communities. These reefs generally support a zonation of benthic communities of algae and animal species including concretions, encrustations and corallogenic concretions.'

'submerged sandbanks' (Natura 2000 Code 1110): 'Sublittoral sandbanks, permanently submerged. Water depth is seldom more than 20m below Chart Datum.'

'submarine structures made by leaking gases' (Natura 2000 Code 1180, Annex V).

The definitions extracted above were meant as guidelines and there is an ongoing debate as to how the definitions may be improved and what features may fall into the habitat classes as defined in EUR 15/2.

The 2001 DTI program of new data acquisition within the northern SEA2 was focused within the Fladen Grounds, where the seabed sediment is dominated by mud and sandy mud (Figures 1, 3). Here a large area of the muddy seabed is cratered by sediment erosion caused by fluid release. This process forms 'pockmarks'. These are the focus of study in the northern SEA2 because they are presumed to be 'submarine structures made by leaking gases', some of which also contain biogenic carbonate 'with a small natural range by reason of their instrinsically restricted area' that under the EU Directives are also worthy of consideration for preservation as 'reefs'. The northern SEA2 is not within the geographical scope of this report.

Seabed sediments in the southern SEA2 are dominated by sands and sandy gravels. Although one site investigation report (Appendix 1: SO/92/040) indicates the possibility of the occurrence of seabed pockmarks in fine sediments in the southern SEA2, this interpretation needs verification. The main features designated for the new scientific research within the southern SEA2 were the sand banks and sand ridges with the research focus on the Norfolk Banks and the Dogger Bank (Figures 1, 3). Some of the sandbanks occur in less than 20m water depth and form isolated features in the North Sea. Research on these sandbanks is covered by the EU Directives because they fall within the definition of 'submerged sandbanks' and are also features worthy of consideration for preservation because they are 'with a small natural range by reason of their intrinsically restricted area'. With their abundant sand eels that find refuge in the sand they are also sites of important food sources for sea mammals and sea birds, the last within the scope of interest covered by the Bird's Directive (79/409/EEC). Where the banks and the swales (or valleys or troughs) between the sand banks and sand ridges banks occur with spreads of seabed gravel with abundant benthos, they may also technically fall within the definition of 'reefs' as specified in the Interpretation Manual of European Union Habitats (EUR 15/2). Other significant environmental features of the sand banks are that as barriers they may dissipate coastal erosion originating from wind-driven sea waves and, by edge diffraction, they may focus sea waves locally onto the coast (Appendix 7, Section 5)

For this report the scope of the BGS research program for the bank, ridge and trough bedforms in the southern SEA2 was specified as:

1. documentation of field observations and integration of geophysical and still-photographic data acquired during the 2001 Kommandor Jack and Vigilance Surveys together with the results of grain size analyses
2. interpretation of the new survey data with existing regional information to provide an improved understanding of the distribution patterns of sediment sources, sediment dispersion pathways, sediment accumulation rates, relict terranes and seabed sediment types

This report includes a geological interpretation of the seabed geomorphological and grain size data with reference to the complete range of populations of the bank, ridge and trough bedforms that have formed in response to near-bottom current flow. It is intended that the interpretations of detailed data of seabed sediments over the Norfolk and Dogger Banks will be used to compare with the computational model of depth-averaged currents for the southern North Sea (Haskoning and D'Olier, 2002). It is also intended that the results should be useful to those biologists who are interested in understanding and mapping variations in the seabed geology and relating them to the modern seabed benthic environment.

Hydrodynamic and sediment flux modelling was specifically excluded from the scope of this research.

1.2 Funding

This research was funded by the UK Department of Trade and Industry, Oil and gas Directorate, Environment and Decommissioning.

1.3 Organization of work

A summary of the work program is shown in Figure 5.

1.3.1 Program management

The SEA2 program of research was managed for the Department of Trade and Industry by Geotek Ltd in partnership with Hartley Anderson Ltd as the Contracting Authorities.

1.3.2 Pre-existing data sources

Pre-existing data integrated into this interpretive report include:

1.3.2.1 Commercial site investigations

These are principally from cable route, pipeline route and well-site and other platform investigations. Exclusive of fisheries, the commercial development of the SEA2 southern area is dominated by production from the mature natural gas fields (Figure 2). Prior to the earliest developments and during subsequent development stages the gas fields and the areas connecting between them and to the landfalls have had detailed site investigations on the seabed and deeper formations. These were either aimed at appraisal of potential geohazards at planned development sites or at acquiring suitably detailed information for foundation engineering design purposes. If aimed at foundation design rather than hazard avoidance, the use of the detailed site investigation data is withheld as long as it has it has commercial value. The geohazard site investigation surveys cover areas of sea bed that are 1km^2 or larger and typically contain interpretation of high-resolution bathymetric, sidescan sonar, sub-bottom seismic, sea bed and shallow sediment sample surveys. The recommendation of the UK Offshore Operators Association is that a copy of the site investigation reports should be sent on a voluntary basis to the BGS for archival and where appropriate, incorporated into published regional geological maps and reports. The site investigation reports archived at the BGS are incomplete compared to the total number of site investigations performed by commerce. With few exceptions the reports contain detailed data on seabed geomorphology and seabed and sub-seabed sediment types that could be applied to benthic habitats research. The contents of the reports archived at the BGS have been summarily appraised (Appendix 2) and suitable data incorporated into this report.

1.3.2.2 BGS regional data, maps and reports (www.bgs.ac.uk)

Interpretations from high resolution seismic reflection profile and sonar data, seabed and shallow samples have been used to compile the published BGS 1:250,000 and 1:1,000,000 scale maps and regional reports. The data presented in the maps and reports cover seabed topography, analyses of seabed sediments and interpretations of Quaternary geology and solid geology for the UK continental shelf (Appendix 3). These outputs incorporate interpretations from high-resolution bathymetric and seabed textural (sediment grain size and sonic backscatter) data acquired from the UK Hydrographic Office as well as from the commercial site investigations. The work was undertaken within a rolling program that was completed for SEA2 by 1994 and for the UK shelf and parts of the deep-water margins by 1995 (Table 2).

Research funding	Dates
Department of Education and Science through Natural Environment Research Council	1966-1975
Department of Energy, Department of Trade and Industry	1975-1995

Table 2. History of research funding for the BGS program of mapping the UK continental shelf

The BGS regional report for the southern SEA2 (Cameron et al, 1992) expands on the data and interpretations contained within the 1:1,000,000 scale maps of seabed sediments (Pantin, 1991) and Quaternary geology (Holmes et al, 1994). Information on the regional patterns and the processes influencing metal concentrations in seabed sediments within the SEA2 area has also been published for 38 elements including aluminium, barium, cadmium, chromium, cobalt, copper, iron, mercury, magnesium, manganese, molybdenum, nickel, lead, rubidium, strontium, titanium, uranium, vanadium and zinc (Stevenson et al, 1995).

1.3.2.3 North Sea Geology Report Number 8

North Sea Geology Report Number 8 was published on the DTI web site www.habitats-directive.org in September 2001 (Holmes *et al* 2001) renamed to www.offshore-sea.org.uk. The geological report was one of a group of specialist reports on pockmarks, fisheries, contaminants, plankton, marine mammals, cephalopods, development activities in both areas of the SEA2 as part of the DTI program of research consultation with the public. Although these preliminary SEA2 environmental reports are currently no longer available from the DTI web site, a copy is available from Geotek Ltd. North Sea Geology Report Number 8 summarizes published works on the existing seabed environment in the context of the geological evolution of the North Sea and the interactions between the natural environment and selected seabed development operations. It summarizes the wider geological setting of the new research results generated from this report and forms part of the deliverables for this project (Appendix 7).

1.3.2.4 Southern North Sea sediment transport study www.sns2.org

The study was completed for a group of nine local authorities with the Environment Agency and English Nature and the dredging industry and part-funded by the Department for Environment, Food and Rural Affairs (DEFRA) between 2000 and 2002. The work was completed by a consortium of Hydraulics Research Wallingford, Centre for Environment Fisheries and Aquaculture Science (Lowestoft Laboratory) and the University of East Anglia (Haskoning and D'Olier, 2002). The southern North Sea sediment transport study focused on the shore and nearshore areas that are mainly outwith the area a of SEA2 but also extended from the coastline to include the Norfolk Banks that were referred to as the 'north Norfolk offshore banks'. The aims of the southern North Sea sediment transport study included models of mid-water current directions and speeds, identification of sediment sources, transport pathways, quantification of the rates and volumes of sediment transport and deposition across the range of particle sizes and temporal scales. Other objectives were the identification of location size, variability of seabed features and evidence for interactions with waves, wind, surge and tidal currents.

1.3.3 DTI 2001 program of new data acquisition

The main DTI 2001 offshore programs of geophysical data acquisition in the SEA2 was executed by Offshore Survey and Engineeering: Geschulschaft fur Seevermessung mbH (OSAE) from the survey vessel SV Kommandor Jack as the operating platform with survey personnel from OSAE and Geotek Ltd.

The shipboard sample acquisition program was executed by personnel from Hartley Anderson Ltd, ERT (Scotland) Ltd and the British Geological Survey operating from the vessel SV Kommandor Jack and by personnel from Hartley Anderson and ERT operating from the Vigilance (Table 1).

Vessel and survey type	Dates
Kommandor Jack: geophysical survey	April - May 2001
Kommandor Jack: sampling survey (>10m water depth)	May 2001
Vigilance: sampling survey (<10m water depth)	June 2001

Table 1 DTI SEA 2 2001 program of new data acquisition

The non-interpretive cruise and laboratory reports on the acquisition of new high resolution data encompassed swath bathymetry, sidescan sonar, chirp profiles (OSAE, 2001), seabed photographs, seabed sediment descriptions (Holmes, 2001) and particle size analyses (Tulloch, 2002). The geophysical data were processed and copied by OSAE Ltd and then distributed by Geotek Ltd in December 2002 for BGS archival and BGS interpretation of data from the southern SEA2 only. The equipment types, the areas of their deployment, maps and title descriptions for the compact discs of data produced are summarized in Appendix 4.

The programs of sampling work for the southern SEA2 were organized in priority order within primary (P) and secondary (S) transects in the area of the Norfolk Banks (Figure 6) and with reference to W and E transects on the Dogger Bank (DBW and DBE, Figure 7).

Where possible, samples were taken in the area of the Norfolk Banks across the crest of the bank in less than 15m water depth (Vigilance) and on bank flanks on the 15, 20 and 30m isobaths (SV Kommandor Jack).

Cameras mounted on a frame were deployed by wire and were capable of video footage and still-frame shots of the seabed in order to assess the variability and distribution of the in-situ seabed sediments and biota. Visual seabed images and sonar backscatter images were also used to preview sediment type in relation to strategy for seabed sampling operations. The Van Veen Grab was deployed for sampling in all of the uncohesive sandy and gravelly ground conditions in the southern SEA2. Samples were split shipboard for analyses of biota, geochemistry and particle size analysis.

1.3.4 Organisation of geophysical, geological and particle size analytical data acquired during the DTI 2001 surveys

Archived 2001 survey data

The geophysical data from the DTI year 2001 SEA2 surveys in the form of hard-copy maps and 700Mb computer discs in dedicated archive stores at BGS Edinburgh. The disc-data has also been archived digitally with appropriate back-up facilities into the corporate Geological Large Object Store (GLOS). Further, the digital and hard-copy of the field geological sample description sheets, particle size analyses and archive specimens of the samples have been registered into the BGS national archive of seabed sediment samples. These samples are thus publicly accessible either by reference to the DTI sample numbering system for SEA2 or the BGS national archive number (Appendix 4). The positions of the SEA2 southern sector seismic reflection data, seabed images and the photographic and particle size data from the samples of the seafloor have also been incorporated into a Geographical Information System (GIS) project for the purposes of generating the images for this report. The disc data from the northern SEA2 have not been assimilated into a GLOS or the GIS. The reference for this report has been entered into the BGS archives but otherwise the report contents remain confidential unless released by the DTI.

The results from the analyses of biota and inorganic and organic chemical compounds and elements from the DTI SEA2 2001-acquired samples are not incorporated into any of the datasets for this report (see 'Aims and Scope' above).

There were 159 samples of seabed taken during the SEA2 surveys of the southern North Sea and it is not productive to detail all the photographic and grain size analytical data in hard copy for this report. Instead the labels that were assigned to the DTI 2001 samples taken on each transect are listed below the titles of the figures dealing with the mean grain size and sorting for each sample . In the Adobe Acrobat (version 5.0) of this report these labels are linked to digital Adobe Acrobat 5.0 (pdf) files in a separate folder with the following contents:

- Seabed photograph(s)
- Graph (s) of particle size / weight %
- Table of weight % of gravel sand and mud
- Table of cumulative weight % of size fractions

Seabed photographs are sometimes excluded from this suite of data, particularly when the sample sites were in turbid water at the bank crests.

One example of hard copy derived from the digital database is given in Appendix 6.

1.3.5 Sampling uncertainties

The survey vessels used for sampling had dynamic positioning. During the seabed photography and sampling operations it was found that the station-keeping capability was possible within a radius of approximately 1.0m.

The sites were sampled some 2-6weeks after the period of the new seabed geophysical survey. Except for transect P10, there was no note made during the sampling of where the sample site was in relation to its position on small to very large transverse bedforms (0.6m->100m wavelength) that were superimposed on the banks and the troughs between the banks.

The mean grain sizes of very large transverse bedforms off the Danish coast are known to fine systematically in the range of 0.9mm (very coarse sand) to 0.1mm (very fine sand) with position across the bedforms (Anthony and Leth, 2002). These observations indicate that overall trends in mean grain size across the Norfolk Banks will also be variable where sampling was across superimposed bedforms.

The sample patterns extended to the deepest parts of the bank flanks on the 30m isobath. This isobath is more or less in the transition zone to the troughs. These extend between the banks where the seabed is scoured by relatively strong-near bottom currents. The risk associated with these samples is that they can be characterised by relict lithic and bioclastic anomalously coarse and poorly sorted sediments that are atypical of the composition of the bulk seabed sediments on the adjacent bank (section 2.5). Because the 30m isobath samples from relict environments may give little information on the function of the banks, discretion has had to be exercised on whether the results from the 30m isobath were incorporated into the interpretation of the systematic cross-bank trends derived from the seabed sediment sample data.

The DTI survey data were acquired in 2001 under non-storm conditions. Variations to seabed sediment grain sizes caused by storms are briefly discussed later in this report.

2. Regional geological setting, sediment sources, sediment pathways and sediment sinks

The modern seabed habitat is a natural synthesis of past and present conditions so that the interpretations incorporated into this report are also derived from seabed and subseabed geological information.

2.1 Geomorphology

The Norfolk Banks in the SEA2 southern area occur where the average modern water depths shoal to less than 40m and are located on a broad topographic high, sometimes referred to as the Southern North Sea Bank (Figure 2). The Norfolk Banks are sited between the Well Bank Flat and the Deep Water Channel, this last with water depths of 40m to 50m or more (Figure 6). The Dogger Bank forms a broad positive feature that extends towards the northeast for more than 120km across the southern North Sea (Figure 2). It is isolated from the shoal-water areas surrounding the eastern UK coast by the deeper waters of the Outer Silver Pit (Figures 2, 7).

2.2 Influence of the sub-seabed geology

With notable exceptions, the seabed sediments are Holocene in age. The Holocene is a climate-defined epoch that followed the Pleistocene epoch within the Quaternary system (age 2.6Ma to present day). The Holocene refers to the interglacial that started approximately 10,000 years ago and continues to the present day. Due to the strong tidal- and wave-induced currents affecting the southern North Sea, the predominantly sand-size (0.06-1.68mm diameter) seabed sediments on the banks are mobile. Thus the variations in the bedforms and grain sizes of the mobile seabed sediments more or less reflect the modern hydrodynamic conditions affecting the seabed. Where the modern mobile sediments are very thin, provide sporadic cover, or are absent, the sediments at seabed or just below seabed are typically relict. In this situation, the composition of the seabed sediments may reflect the depositional environments of early Holocene or pre-Holocene sediments that were deposited under widely different climates and depositional conditions to those of the present day. Exposed or relict sediments can therefore make a significant contribution to the variability in the composition of the modern seabed substrates.

From the regional perspective the mega-scale geometry of the whole North Sea Basin has been inherited from a 30Ma-long history of sedimentation styles driven by climate change and crustal warping (Figures 1, 2, 3 in Appendix 7). The meso-scale geometry of the submarine banks and ridges formed at seabed within the southern North Sea Basin were formed at times extending from the last major glacigene period, which started prior to 22,000 years ago, but their shaping more or less continues to the present day.

Approximately 18,000 years ago a terrestrial ice sheet originating from northern Britain was at its maximum extent into what is now the southern North Sea. The ice sheet deposited a blanket of diamicton consisting of unsorted, stiff to hard, cohesive muddy and gravelly sediments. The boundary between the diamicton and firm to hard muds with sediments of mixed soft cohesive and uncohesive properties cuts across the area enclosing the Norfolk Banks (Figure 8). The importance of this boundary is that the sediments to the north and south of the limit of the diamicton are potential sources for mobile sands feeding to the banks. The rates and products of erosion of the sediments are influenced by the sediment cohesive strengths and size range of particles contained within the sediments. The diamicton and other over-consolidated muddy cohesive sediments are much harder to erode than the cohesionless sandy sediments and muddy soft cohesive sediments. Thus the SE heads of the Norfolk Banks have been and continue to be close to potentially rich sources of relatively easily erodeable sediments since their early stages of formation (Figure 8).

Very rapid post-glacial marine flooding and erosion of the Southern North Sea Bank occurred in the mid-Holocene at around 8,500 to 7,000 years before present. The Norfolk Banks formed from mobile sands as tidally-dominated linear sand banks and open shelf sand ridges since the mid-Holocene (in section 5, Figure 7 Appendix 7). Sands with minor muds and gravels therefore typify the internal and external (seabed) compositions of the Norfolk Banks.

The Dogger Bank is elevated some 20-30m or more compared to the surrounding seabed and shoals to less than 20m below sealevel in an area known as the SW Patch (Figure 7). In contrast to the Norfolk Banks, the bulk of the Dogger Bank consists of geological formations with mainly firm to hard muds and gravel (Figure 10). These sediments were deposited from outwash input to standing (lacustrine) water that was trapped in an enclave formed at a former ice-sheet margin during the last glaciation (in Figure 7, Appendix 7). Subsequently, the ice retreated and the Dogger Bank was exposed as a large-scale positive feature that resisted erosion during its post-glacial sub-aerial exposure and then subsequent marine flooding of the SEA2 area. The bulk of the Dogger Bank is therefore predominantly a cohesive mud bank that was deposited prior to the early Holocene marine transgression. Other smaller banks, Cromer Knoll, for example may also form from upstanding muds or diamicton (Figures 6, 8). Banks such as may be included within a classification system for sandbanks because of the sand-dominated seabed sediment but not because of the composition of the bulk of the bank.

The geological evolution summarized above is important because it demonstrates that the Norfolk Banks and the Dogger Bank have different sub-seabed compositions that influence their stability. Whereas some of the Norfolk Banks may be conceivably mobile with changing sealevel and coastlines within the next several thousand years, the history of the Dogger Bank indicates that it will be essentially stable.

The Inner Silver Pit, Sole Pit, Coal Pit, Well Hole, Botney Cut and the Markham's Hole form elongate, over-deepened and enclosed paleo-valleys that have only been partly filled with unconsolidated sediments (Inner Silver Pit, Sole Pit, Well Hole, Coal Pit: Figure 6). The paleo-valleys may have been moulded by erosion underneath a grounded ice sheet and later by tidal scour (Balson, 1999). The largest of these is the Inner Silver Pit some 60km long, 10km wide and with a maximum shoulder-to-axis depth of approximately 50m. Only one sample transect across the Coal Pit has been included in the SEA2 program of new data acquisition.

2.3 Currents

The shelf area is tide-dominated with a predominantly macro-tidal range along and offshore from the Norfolk coast in the order of 2-6m. The depth-mean tidal current contour for 60cms^{-1} speed encompasses the distribution of the Norfolk Banks and also the medium to very large transverse bedforms (Dyer, 1982). The strongest near-shore currents are associated with the nearshore shoal-water areas of rock cropping just below the seabed and also with extensive near-shore sea bed gravel spreads (Figures 3, 8, 9). During the spring tides the maximum mobile grain size ranges between 2-4mm (granular gravel) adjacent to the coast but at further distances from the coast it includes all the sand-size classes (Figure 35 in Haskoning and D'Olier, 2002).

In winter a plume of high concentrations of suspended sediments in surface waters extends offshore from Norfolk to the NE and over the central and southern parts of the Norfolk Banks. The position of the winter plume may possibly be correlated with the eastwards diversion of suspended sediment carried by strong nearshore currents originating from the Humber, convergence with sediment from the south and the directions of depth-averaged spring, neap and residual tides across the Norfolk Banks (Figure 12). The plume has also been correlated with the effects of winter wave action on the seabed (Haskoning and D'Olier, 2002) at sites where there is rich potential for sourcing seabed fines if the seabed is stirred up to expose sub-seabed formations (Figure 8).

Departures from the symmetry of tidal ebb and flow currents occur with the bias introduced by surge wind and wave-driven currents and interaction with the existing seabed topography and are described by Haskoning and D'Olier (2002). Because of this variability, the movement of seabed sediments over the southern North Sea Bank is potentially complex with time and is rarely predicted with a dominant sediment pathway. An exception to the complexity may occur as a result of forcing during strong storm surges originating from the north. The surges can occur as separate or composite events and as they move southwards into the shoaling water in the North Sea they are accentuated and force changes to linear sediment transport paths to the south and sub-parallel to the coastline in the area of the Norfolk Banks (Figure 46 in Haskoning and D'Olier, 2002). The DTI 2001 surveys were not undertaken during a period of storm surge.

2.4 Classification and environmental significance of sandbank bedforms

The European Union maintains a Submerged Sandbanks Database where the largest of the banks in the southern SEA2 are individually numbered and classified in terms of name, location, water depth, geometry and sediment composition. The classification system as described by Christiansen and Jones (2001) does not take into account processes of formation or environmental significance. This report adopts the terminology used for describing the geometries of banks but does not undertake to update the field data as defined in the EU database for sandbanks for SEA2 (Appendix 1).

The Norfolk Banks and the smaller bedforms superimposed upon them have accumulated and moved as a result of bedload sediment movement as one component of the total sediment flux (Figure 13A). The bedforms provide information pertinent to interpreting the bedload sediment pathways, seabed stability and relative deposition rates (Figure 13 B, C). The modern seabed is therefore active as it is adjusting to the modern hydrodynamic regime. Bedform indicators of near-bottom current alignment such as sand streaks and sand ribbons are most commonly observed in areas that are relatively starved of mobile sands do not feature on the Norfolk Banks.

The few high-resolution profiles showing the internal geometries across the Norfolk Banks indicate that the bulk of the bank 'heads' occur with mainly aggrading strata, parts of which have been eroded at the flanks. In contrast, parts of some of the main body of the Norfolk Banks and their northern 'tails' occur with mainly prograding strata (Figure 14). Progradation on the bank tails is demonstrably a recent historical process and is probably occurring at the present day (Figure 15). The aggradation may be interpreted as a sedimentary response to early to middle Holocene sealevel rise and the erosion and progradation, also at the bank heads, the sedimentary response to later Holocene net sand movements. If it is assumed that the that strong currents have maintained an overall bank linearity then the bank heads function to more or less control the geometry and stability of the bank tails. This is an important observation because a qualitative estimate of potential bank stability can be obtained from interpretations of internal bank geometry. Further, any changes to head geometry will probably be rapidly reflected in the smaller-bulk tails, so that it is the banks heads that should be focus of attention for environmental conservation.

Smaller bedforms are superimposed on the Norfolk Banks and Dogger Bank and intervening troughs. They importantly feature as separate class of flow-transverse bedforms (termed here-after as transverse bedforms) to the near-bottom current flow (Figure 13). These transverse bedforms are important features of the sand-banks but for reason of their size and mobility they are excluded from the descriptive formats in the European Union Submerged Sandbanks Database. In SEA2 they are observed as 3-dimensional bedforms, that is, as bedforms with curved axes (terminology after Ashley *et al*, 1990).

The smaller transverse bedforms may respond relatively quickly to eddies and vortices, for example with sea-waves, and to daily changes of strength and direction of the neap and spring, flood and ebb tidal streams. The larger bedforms may only be measurably mobile on a time scale of days to months or longer. Because of their different orientation compared to the named sand banks and sand ridges and being at least an order of magnitude smaller than the named sandbanks, the transverse bedforms are clearly in a different class. The transverse bedforms are typically referred to in the older literature and in the commercial site investigation surveys in order of increasing size class as ripples, mega-ripples and sand-waves. Fields of such bedforms are commonly reported adjacent to each other or may be superimposed and because of variations in size and occasionally superimposed spatial patterns they may appear, at first, to fit into size-based heirarchical systems. Table 2 summarizes the typical ranges of their dimensions as described in the commercial site investigation reports from the southern SEA2.

Bedform	Trough to crest (height)	Distance between crests (wavelength)
Ripples	<1cm-10cm+	5cm-60cm+
Megaripples	10cm to 3m+	60cm to 30m+
sand waves	3m to 5m+	30m to 1000m+

Table 3. Typical ranges of dimensions of transverse bedforms reported in commercial site investigation reports in the southern North Sea. Wavelength division between megaripples and sandwaves follows McCave (1971)

From the global viewpoint, however, the sizes of the sub-aqueous and flow-transverse bedforms cluster into two main populations. These are separated by few bedforms between approximately 0.5 to 1.0m spacing. In nature there is no bedform size discontinuity between ‘megaripples’ and ‘sandwaves’ in the 1-1000m+ wavelength class so that the larger transverse bedforms are recognized as a single genetic population. For this report the identity of ripples with bedforms less than approximately 0.6m wavelength is adopted and potential for historical ambiguity associated with the use of terms ‘megaripples’ and ‘sandwaves’ is avoided. Instead, an arbitrary division of the larger transverse bedforms into classes with lengths (L) between crests or troughs of small 0.6-5m, medium 5-10m, large 10-100m and very large >100m is adopted after Ashley *et al*, (1990) (Figure 13b). The estimates of the corresponding bedform heights observed from crest to trough (H) are scattered around a curve fitting the equation $H=0.677L^{0.8098}$ (Flemming, 1998). Because the bedform heights between the crests and troughs are more easil remoulded than the bedform wavelengths, variations in transform bedform heights are not incorporated into the size classification system adopted for this report.

As the consensus of opinion is that the larger bedforms generate a boundary layer in which the smaller bedforms are locally stable, the superposition of transverse bedforms has little significance with reference to the strength of the near-bottom hydrodynamic regime (Ashley *et al*, 1990). The consensus is that the small superimposed bedforms migrate through large fields of bedforms because of the relative volumes of the bedform sizes and the time available for bedform migration.

The significance of the mobile superimposed bedforms is that they are indicators of locally very high sand deposition or erosion rates (Figure 13). For example repeat commercial surveys within a nine-month interval on the NE flanks of the Broken Bank have demonstrated that the crests of very large transverse bedforms (wavelength >100m) have moved laterally by at least 25m. At the same location, the average seabed elevation, registered by comparing the depths of the bedform troughs, appeared to have deflated by approximately 1 metre with reference to lowest astronomical tide (Appendix 2: SO/91/042; SO/91/126, Figure 6). The difference of average seabed elevation is presumed to be within the possible range of variation in seabed elevations formed when climbing (aggrading) bedforms are created, destroyed or move on (Figure 12, C).

The inverse correlation of bedform volume with stability and the semi-endorsed nature of the sandbank system summarized previously are environmentally important as they provide possible qualitative insights to habitat variation within one sediment size class.

2.5 Mean grain size and bulk sediment composition

The regional model demonstrated that mean grain sizes of the modern seabed sediments on the Norfolk Banks register predominantly within the sand-size class (Figure 9). In contrast, the shoal areas on the Dogger Bank contain relict patchy gravels and a variety of sands and gravelly sands at seabed that are clearly not in hydrodynamic equilibrium with non-storm conditions. These have originated when minimal disturbance of the superficial sediments on the Dogger Bank has exposed the underlying formations with very different properties to the seabed sediments (Figure 10).

Sea-bed sediments in the troughs between the Norfolk Sandbanks vary from poorly sorted to well sorted medium sands, gravelly sands and, more rarely, sandy gravels. The biogenic carbonate in the sand size fraction in the troughs varies from approximately 20 to 80 weight % and in the gravel size fraction from 20 to 100 weight % (Harrison et al, 1997; Balson, 1990). Holocene sediment thicknesses in the troughs typically vary from less than 5m to a few centimeters and over the sandbanks vary from 10 to 30m or more thickness. The sea bed sediments on the Norfolk Sandbanks are predominantly very well sorted to well sorted and consist of fine to medium quartz sands with 5 to 20 weight % biogenic content in the sand fraction (Harrison et al, 1997; Balson, 1990). The overall trends of decreasing biogenic carbonate and finer grain size across the sediment from trough to flank (Figure 13) may then reflect changing carbonate benthic productivity, an overall carbonate loss with sediment transport and sorting towards bank and weaker near-bottom current flow over the banks (Houbolt, 1968).

One impact of carbonate input to interpretations of grain size and sorting is that carbonates are commonly characterised by plate-like and relatively poorly rounded grains that are not hydraulically equivalent to silico-clastic grains of the same diameter. Although inputs from biogenic populations to sediments may mean that variations of mean grain sizes are not correlated with modern hydrodynamic conditions, their inputs have little impact on interpretation of mean sand size variations across the banks because they are dominated by non-carbonate clastic grains (Figure 14).

2.6 Process Models for Norfolk Bank, Dogger Bank

Published variations of sediment mean grain size can be integrated with bedform facing directions, hydrodynamic models and large-scale bank structure to construct a synthesis of bank properties and function (Figures 14 & 15). The major gaps of scientific knowledge associated with the model arise as a result of its synthesis from disparate components. The data collected for this research are aimed towards bridging the information gap required for a regional synthesis and to integrate seabed geomorphology and seabed sample data for tests of across- and along-bank processes.

3. Results

The order of the areas covered by this report reflects that of the SEA 2 survey priorities assigned by the Contracting Authorities to the primary (P) and secondary (S) transects.

3.1 Norfolk Banks

The Norfolk Banks form the largest set of the open shelf tidal sand ridges in the North Sea. If defined within the 20m isobath the Haisborough Sand, Hammond Knoll, Winterton Ridge, Hewett Ridges, Smith's Knoll and the Leman, Ower, Inner, Well, Broken, Swarte, Viking and Indefatigable Banks vary from approximately 20-55km length. They have crest spacings varying from approximately 5km to 11km (Figure 6). Except for Indefatigable and Viking Banks all have crest depths less than 10m below the lowest astronomical tide and rise from inter-bank troughs ranging from approximately 30m to 40m or more below the lowest astronomical tide. Local seabed gradients are up to 7° on the NE-facing and lee flanks of the Norfolk Banks but are generally gentler on the SW flanks where they are 1-2° or thereabouts.

3.1.1 Ower Bank (P1 sample transects)

The Ower Bank has a zig-zag dislocated crest situated between Leman Bank and Inner Bank. The crest dislocation separates the Ower Bank A (with sample transects P1 and P1.1, Figure 6) which is SE from the Ower Bank B (with sample transects P1.2, P1.3 and P1.4, Figure 6), both of which are asymmetric linear in plan. Water depths vary from less than 10m at the ridge crest to more than 40m at a location where the bank extends towards the south east to the margins of the Deep Water Channel (Figure 6). The BGS regional mapping indicates that the major part of the bank contained within the 20m isobath consists of sand (Figure 9). Patches of gravelly sand are situated in the deeper water to the SW of Ower Bank A. A more extensive zone of slightly gravelly sand and gravelly sand occurs to the south west of Ower Bank B. There is a predominance of sheet-form gravelly sands in the deeper water adjoining the NE flanks of both the Ower Bank A and the Ower Bank B.

The shaded image from the SW flank of Ower Bank A (Figure 15) shows very large to large transverse bedforms with curved crests orientated approximately N180°E to N30°E and with wavelengths varying from approximately 700m to less than 100m. Average bedform heights are less than 2m between approximately 10m and 25m water depth. An area of smaller transverse bedforms with minimum wavelengths less than 60m occur between approximately 20 and 30m water depth and are aligned at approximately N40°E. These adjoin a separate field of very large transverse bedforms on the lower flank at around 30m water depth with bedform crests orientated at around N20-30E. Subsets of the smaller bedforms occur in both of the fields with the larger bedforms where they are aligned at slightly different angles. The chirp profiles indicate bedform facing directions and an overall sediment transport direction to the NW, many of the largest bedforms featuring small 'stacked' bedforms on the stoss slopes (Figure 15).

A shaded image has been acquired on the NE flank of Ower Bank B at a site part of the area where the crests of Ower Bank A and Ower Bank B are separated by a low col (Figures 6, 16). Large-scale transverse bedforms with wavelengths less than 80m characterize the seabed below approximately 18-22m water depth and are strung out as fields some 200m to 500m or wide in seabed furrows with edge to axis depths of less than 1m (the isobaths are not illustrated). Two shallow rounded closed depressions in the seabed some 200-250 diameter and less than 1m depth occur in the deeper water in the NE of the survey area. A field of large to very large transverse bedforms with trough to crest heights less than 1m, and wavelengths up to approximately 100m occur in approximately 10-22m water depth. These decrease in height and wavelength adjacent to the shallower parts of the bank crest, presumably because of their destruction by wave energy. The SE-facing steeper faces on most bedforms observed from the seabed shaded relief image and the chirp profiles indicate that net sand transport was towards the SE at the time of survey. This is an important observation as the swath survey crosses the nose of Ower Bank A. The generic model indicates that the bedforms may have opposing facing directions in this zone (Figure 15). The absence of bedform evidence for this zone indicates either that the survey area was not large enough or that the zone did not exist at the time of survey.

The seabed sands vary from fine to medium grain size (Figure 17) and are moderately well sorted to very well sorted.

On Ower Bank A transect P1 there appears to be an overall decrease of mean grain size in sand size sediments with 20-10m shoaling water. In transect P1.1 the fine to medium sand-size sediments on the SW flank increases in mean grain size with shallowing water towards the bank crest. The samples at equivalent water depths on the NE flank fine towards the NE and are overall finer than those on the SW flank. Abundant peat fragments were found in the sample P1.1A in approximately 30m water depth. The peat occurred with putrid-smelling fine sands approximately 5cm below seabed (Holmes, 2001). The NE flank of Ower bank A shows a trend of overall decreasing mean grain size towards the NW and on the SW flank an overall decrease of mean grain grain size towards the SE. The fining trends on the SW flank are opposing those of the directions of net sand transport that can be inferred from the bedform facing directions. The fining trends of sand mean grain size on both flanks indicates a possible anti-clockwise circulation around the bank which is opposite to that expected from previous research (Figure 15).

On Ower Bank B the mean grain size data from the samples of the bedforms in transect P1.2 show that the sea bed sediments consist of medium to fine well sorted to very well sorted sands. The mean grain size of the sediments decreases overall from the SW flanks with shoaling water over the crest of the bank and then continues to fine with increasing water depth over the NE flanks. Samples taken during the 2001 DTI survey from the NE flanks had a strong fish smell occurring with patchily developed weak grain bonding from gelatinous organics (samples P1.2E and P1.2F in Holmes, 2001). Swath data are not available from the SW flank. Sea bed samples on the crest and NE flank on transects P1.3 and P1.4 are overall finer than those on the SW flank. Transect P1.4 shows a decrease in mean grain size with increasing water depth between the 20 and 30m isobaths on its NE flank.

Except at the southernmost transect P1 there appears to be an overall finer seabed sand on the NE-facing flanks of Ower Banks A and B compared to the SW-facing flanks. Between transects P1.2 and P1.4 and within the confines of the 20m isobath there is a trend of north-west fining sand on the SW flank and south-east fining sand on the NE flank. The fining trends on the NE flank are consistent with the bedform facing directions observed across transect P1.2. The along-flank fining directions on Ower Bank B are consistent with the model for clockwise sediment circulation.

The mean grain size trends summarized above indicate that as well as being geomorphologically dislocated from each other the seabed functions of the Ower Banks A and B are also separated.

3.1.2 Smith's Knoll (P2 transect)

This plan-linear sand bank is approximately 80-90km east of Norfolk. Its axis is strongly concave to the west and sub-parallel to the Norfolk Coast (Figure 9).

A sidescan sonar image from a small area on the SW flank, which includes only part of the sample transect, shows low and almost uniform seabed backscatter but the chirp profiles from the same area show that large-scale bedforms are migrating to the northwest (Figure 18). No large-scale bedforms were surveyed on the NE flank of the bank.

The flank seabed samples comprise medium to very fine well to very well sorted sands with a trend of overall grain size fining towards the NE across both flanks (Figure 19).

The medium sand taken from approximately 33m water depth at the base of the flank was reported with pebble size (>4mm) peat fragments (sample P2F in Holmes, 2001).

3.1.3 Indefatigable Banks (P3 transects)

Situated approximately 95 km to the NE of the nearest Norfolk coast, the Indefatigable Banks consist of two low main banks as defined by the 20m isobaths (Figure 6).

The survey with swath bathymetry and sidescan sonar survey over a NE-trending transect on the NW Indefatigable Bank reveals a plan-irregular meso-scale seabed morphology (Figure 22). This is in contrast to the bank crest that exhibits a smooth seabed in less than approximately 15m water depth below lowest astronomical tide. The areas of plan-irregular bedforms on the flanks correspond to the areas with higher seabed backscatter on the sidescan sonar.

The P3 transect over the SE bank consists of moderately to well sorted fine sands where on its SW flank the mean grain size increases with shoaling water onto the crest. There is also an abrupt coarsening of mean grain size on the NE flank (Figure 16). There are no profile data on the sample transect with which to image the sub-seabed geology.

The P3.1 profile of mean grain sizes shows an overall fining of medium sand-size seabed sediments with shoaling water across the SW flank and crest. In contrast the P3.1 samples at sites C, B and A consist of coarse sands and coincide with an area where the chirp profiles show that truncated internal reflectors appear to crop at seabed. The variations of coarser grain size, poorer sorting and sub-seabed profiles are interpreted to suggest that the NE flank of the bank is being strongly eroded so that the coarse seabed sands sampled there are relict.

The SE Infatigable Bank is in an area where the seabed is underpinned by sand whereas the NW Infatigable Bank is within the limit of the last glaciation and is underpinned by a diamicton

(Figure 8). It is thought that as well as being relict, the overall coarser sediment composition on the NW Indefatigable Bank may reflect local provenance from the coarse sediments sourced from with the diamicton.

3.1.4 Leman Bank (P4 transects)

This sand bank is asymmetric linear in plan and situated approximately 40-50km NE of the Norfolk coast. The wider margin is at the southern end of the bank. The P4 sample transect crossed the southern Leman Bank where it is curved sub-parallel to the coast and is less than 10m below the lowest astronomical tide. The chirp profile data show an overall direction of superimposed bedform movement towards the NW on the SW flank with medium to large bedforms between approximately 40 to 20m water depth and very large bedforms with stacked configuration indicative of high deposition rates between 10 to 20m water depth (Figure 22). The P4_1 transect crossed the middle section of the bank and is without swath bathymetry or sidescan sonar data (Figure 17).

The grain analyses from the flanks show the seabed sands consist of moderately well sorted to very well sorted medium to fine sands. No large-scale shifts or significant gradients of mean grain size were observed between the NE and SW flanks of the bank on the P4 transect across the bank head. On the P4-1 transect the sediments fine overall towards the NE so that those on the NE flank are finer than those at equivalent water depths on the SW flank.

3.1.5 NE extension of Haddock Bank (P5 transect between Outer Dowsing Shoal and Sole Pit)

This transect is sited approximately 30km to the north west of the main area of the Norfolk Banks and approximately 50-75km north of the Norfolk coast (Figures 6, 23). The eastern sector of the P5 transect runs across a low bank, the 20m isobath of which has a highly irregular plan geometry that encloses the northern extension of the Haddock Bank. Sub-seabed sediments underlying the northern Haddock Bank transect P5 entirely consist of a diamicton that has presumably sourced the highly variable grain sizes and poortly to very poorly sorted sands, gravelly sands and sandy gravels at seabed (Figures 8, 25).

Grain size analyses show that the transect has crossed sediments consisting of moderately to very poorly sorted medium to very coarse gravelly sands and sandy gravels with bi-modal grain size populations and the sandy gravels predominating. At its NE end the transect crosses a spread of sand that has been mapped by the BGS on the low bank with less than 1% gravel (Figure 8). Such well-sorted sands were not found during this survey, instead the seabed sediments were found to consist of sandy gravels and gravelly sands. The results from the 2001 data are consistent with an interpretation that the mobility of the seabed sediments in the areas outside the Norfolk Banks will cause changed to regional patterns of seabed sediment class with time.

3.1.6 Well Bank (P6 transect)

Well bank is situated approximately 60km NE from the Norfolk coast and is asymmetric linear in plan with the wider bank at the south end. The P6 samples are well to very well sorted fine sands that except for the deepest water sites consistently fine to the NE across the main part of the bank (Figure 26). The P6 transect is adjacent to commercial site investigation profiles (Figure 6: SO/89/250) indicating well developed internal progradation of the bulk of the main body of Well Bank towards the NE.

3.1.7 Viking Banks (P7 transect)

Situated some 83 to 91 from the Norfolk coast, the Viking Banks are linear in plan shape but have a more irregular plan shape to the north. They consist of two main low banks, an east and west bank, with their crests deeper than 10m below lowest astronomical tide (Figure 6). The west bank is overall shallower than the east bank and the chirp profiles indicate that it locally shoals to less than approximately 18m water depth (Figure 25). The chirp profile surveys show that where the banks are side-by-side they are partly merged and except for the crest of the west bank, the seabed is characterized by medium to very large sinuous bedforms. The largest of these bedforms show maximum crest to trough heights of more than 5m (Figure 25). The bedforms on the SW-facing flanks of the west bank are asymmetrical with their steepest slopes indicating that the dominant sediment transport direction at the time of survey was to the NW towards the bank crest. The bedforms on the NE-facing flanks of the west bank are asymmetrical with their steepest slopes indicating that the dominant sediment transport direction was to the SE towards the crest. These styles occur with bedform vertical aggradation indicating that the the middle to lower flanks of the bank were being rapidly built up at the time of survey. In contrast, mergence of the bedforms with the smooth topography of the west bank crest and the micro-rugose appearance of the bedforms on the east bank crest are interpreted as evidence for seabed erosion on the bank crests. The patterns of forward curvature of the arms of the sinuous bedforms are consistent with their smaller volumes and relatively rapid advance with the near-bottom currents.

Unfortunately the P7 sampling transect was offset from the area of detailed geophysical survey (Figure 26). The sediments on the P7 transect across the west bank are moderately well sorted to well sorted medium to fine sands that decrease in mean grain size and become better sorted with shoaling water on both flanks of the west bank. Therefore the bedform geometrical styles and grain size analyses appear to provide consistent evidence for overall transport of sediments towards the crest of the west Viking Bank at the time of survey. In contrast, there are coarser sands within a hollow in the crest of the east Viking Bank (Figures 25,26). The patches of coarser sediments are tentatively correlated with relict sediments and local sea bed scour.

3.1.8 Race Bank (P8 transect)

This is an overall NW trending and smooth curved west flank that is concave towards the land but which shows an irregular plan shape and indentations caused by large scale bedforms that are trending east on its eastern flank. It is a low bank that is defined by the 10m isobath and occurs 20-30km north of the Norfolk Coast (Figure 6). A second low bank with a more complex morphology occurs just to the north of the main Race Bank and has also been sampled on this transect. The two banks are set in an area that is underpinned by the diamicton deposited within the former limits of the last glaciation (Figure 8).

The crest sample from Race Bank (P8B) consists of a poorly sorted slightly gravelly medium sand but a single sample (P8C) from its NE flank consists of a well sorted medium sand (Figure 27). Samples P8D and P8E on the bank sited to the north of Race Bank consisted of poorly to very poorly sorted gravelly coarse sands and P8F further north east consists of very poorly sorted sandy gravel. The overall trend is for patchy predominantly sandy sediments on the main Race Bank coarsening to gravelly sands and sandy gravels to the NE. Although this trend agrees with the meso-scale patterns of seabed sediment classes that have been previously established from the BGS regional mapping (Figure 9) further interpretations have not been possible because of the lack of more detailed topographical survey data for the 2001 sample sites.

3.1.9 Haddock Bank (P9 transect)

Sited some 40-50km NE of the Norfolk Coast and to the north-west of the Leman Bank, the Haddock Bank forms a low bank with an irregular plan shape in more than 10m and less than 20m water depth (Figure 6).

The sea bed sediments on the west bank consist of very poorly sorted medium sands on the west flank in approximately 30m water depth to medium to fine well sorted to very well sorted sands further east. The sands show a more or less steady decrease in mean grain size of the sand fraction from the SW to the NE across the bank complex (Figure 23).

3.1.10 Broken Bank to Swarte Bank (P10 transect)

The detailed survey area, the long axis of which is orientated towards the north, connects the tail of Broken Bank and an unnamed sand bank occurring SW of Swarte Bank and orientated ENE. Water depths in the swales/troughs between the bedforms range from approximately 27m in the south to less than 21 m in the north (Figure 30).

Large to very large transverse bedforms occur with wavelengths varying from less than 200m to more than 1km and bedform axes orientated at approximately N35-45º E. The largest bedforms average approximately 1000m wavelength (Figure 28, bedforms (1) to (5)) and exhibit more than 4m crest-to-trough heights. Asymmetries indicate that the large-scale bedform facing was to the NW in the largest northern survey area and to the SE in the southern survey area adjacent to Broken Bank. The intervening troughs to the largest bedforms occur with bedforms with 1-3m crest-to-trough height. The axes of these smaller bedforms vary from sub-parallel to the largest bedforms to an orientation of approximately N70º E. Their smaller volume arm commonly curve ahead of facing directions at locations where they merge with the crests of the very large bedforms (Figure 30). The shaded relief image and chirp profile data indicate that these smaller bedforms face towards the crests of the very large bedforms. The sidescan sonar recorded a lower backscatter over the bedform crests. Linear targets with high backscatter are tranverse to the directions of the bedform axes and are interpreted as possible cables or pipelines (Figure 24).

The samples range from medium gravelly moderately sorted sands to the very well sorted sands. With one exception (G) the mean grain sizes of the samples from the crests of the largest bedforms group around coarser mean grain sizes than the group of sediments from the intervening troughs. Samples from the troughs in the medium to large bedforms show no systematic overall fining along the transect. At sites P10 D-L the crests of the very large bedforms show overall fining and better sorting towards the sandbank consistent with the transport of medium sand towards the bank.

3.1.11 Broken Bank (S1 transect)

This plan-linear bank is situated between the Swarte Bank to the NE and the Well Bank to the SW and is approximately 70km NE of the Norfolk coast (Figure 6).

There is an overall decrease of grain size in the medium to fine sand classes towards the NE (Figure 26).

3.1.12 NW extension of Swarte Bank (S2 transect)

The transect covers an irregular plan low bank with complex elevation geometry. The outside boundary of the bank complex is confined by the 20m isobath that has extended from the Swarte Bank to the NW (Figure 6).

Samples vary in mean size from gravelly coarse sands in the deeper water swales to the SW and NE of the bank to medium to fine well sorted to very poorly sorted sands on the main part of the bank. The trend is for an overall fining with shoaling water (Figure 25).

3.1.13 Cromer Knoll (S3 transect)

The Cromer Knoll is an irregular plan bank. The transect is approximately 40km NNE of the nearest point on the Norfolk coast and is sited at least 20km to the north of the southern limit of the last ice sheet (Figure 8). The BGS map data show that seabed comprises relict gravel resting on diamicton (Figures, 8, 9).

The samples confirm that the seabed around the knoll consists of a predominantly gravel spread at seabed. Sediments very from moderately well sorted to very poorly sorted gravelly sands and sandy gravels to a moderately well sorted medium sand (S3A) on the knoll crest. The samples are too widely spaced to establish if trends in mean grain size exist across the bank within the medium to fine sand class (Figure 26).

3.1.14 Inner Bank (S4 transect)

Situated between Ower Bank to the west and Well Bank to the east this transect is approximately 55 km from the nearest point on the Norfolk coast. The bank has a linear plan with a crest that is less than 10m below the lowest astronomical tide (Figure 6).

Sea bed sediments are well sorted medium sands on the SW flank and well sorted fine sands on the bank crest and on its NE flank. There is an overall and average fining of graphic mean grain size with position across the bank towards the NE.

3.1.15 Swarte Bank (S5 Transect)

This bank is approximately 75 km the nearest point on land and is sited between Broken Bank to the west and the Viking Banks to the east. The plan shape is asymmetric linear with the wider bank at its south end. The sample transect is across the northern half of the bank where its crest is less than 10 below lowest astronomical tide (Figure 6).

The mean grain sizes of the seabed sediments fall within the fine sand size class and vary from well sorted on the NE and SW flanks to very well sorted on the crest region. Samples on the NE flank are finer than the samples taken from equivalent water depths on the SW flank (Figure 25).

S6 transect: no sediment samples were submitted for analysis

3.1.16 Coal Pit (S7 transect)

This transect is across a closed basin, the southern margin of which is approximately 65 km from the nearest Norfolk coast (Figure 6).

The finest sand sediments occur in the axis of the deep-water basin and samples higher on the flanks vary from fine sands to slightly gravelly sands and gravelly sands (Figure 26).

3.1.17 Haisboro Sand (S8 transect)

This is a linear plan bank situated approximately 15-20km from the Norfolk coast. The Haisboro Sand is the western-most bank of a zig-zag pattern of connected banks (Figure 6). The transect sampled only the SW flank of the bank.

The samples are all within the fine sand class and are well sorted to very well sorted. Between approximately 20m and less than 10m water depth the sediments are systematically finer with shallowing water depth (Figure 28).

3.2 The Dogger Bank

The Dogger Bank is an overall asymmetric linear bank with its broadest end facing to the west (Figure 1). North-orientated survey transects have been taken on the Dogger Bank situated adjacent to the Silver Pit and to the west of an area of slightly elevated topography locally known as the South West Patch (Figure 7). An overall planar seabed with small mobile bedforms rises gently at gradients less than 0.2° from approximately 33m water depth to 25 m water depth and then at approximately 1.5° average gradient between the 25m and 15m isobaths. A commercial site investigaton report indicates that parts of the Dogger Bank are characterized by patches of small-to-medium-size mobile bedforms (SO/92/110, Figure 7). Such bedforms were not resolved during the DTI 2001 surveys.

3.2.1 Dogger Bank East

The Dogger Bank east (DBE) transect is elongated and has been divided into 5 segments for ease of description (Figure 31).

The deeper-water areas occurring adjacent to the southern flank of the bank are characterised by low backscatter and slightly shelly fine sands on an essentially planar seabed (DBE A, Figure 32). In sample DBE B the gravel component of the slightly gravelly sand consists of articulated and broken shells and lithic fractions of sand and gravel associated with seabed scour (Figure 32). High backscatter occurs in approximately 26m water depth at the foot of southern flank and is also associated with gravelly mixed shell and lithic sands (DBE C, Figure 33). The seabed on the southern flank of the bank in approximately 15-21m water depth occurs with fine very well to well sorted slightly shelly sands (DBE D, Figure 33) as are the smooth areas of the bank crest in approximately 15-17m water depth (DBE E, F, G, H, Figures 33, 34). The seabed photography indicates that the gravel fraction recorded from the crest in DBE F and G consists of scattered large shell material (Figures 33, 34). Seabed in approximately 16 to 17m water depth between sites DBE G and H is characterised by enclosed round to irregularly-shaped hollows that are in places more than 0.4m deep and 100m diameter (Figure 34). The high sonar backscatter from the hollows indicates that some contain discrete hardgrounds. The high backscatter returned from the hollows has not been calibrated by sampling. In contrast, the seabed within the northern area of survey is characterised by much larger patches of high backscatter with irregular, many elongated, plan boundaries. The high backscatter predominantly occurs within hollows that vary from less than 100m to more than 1km length, the largest of which may be more than 3m deep from shoulder to trough. Samples DBE J, K taken from the high backscatter from these hollows consisted of a muddy sandy gravel, the gravel consisting of poorly sorted shells and lithic clasts (Figures 35, 36).

3.2.2 Dogger Bank West

Sited approximately 15 km to the west but parallel to the DBE sample transect, the DBW sample transect is in an overall slightly deeper water setting than the DBE transect (Figure 7). The sample transect is offset to the east from the detailed geophysical site investigation survey (Figure 37).

Sediment sample grain size analyses and the seabed photography indicate that the seabed is characterised by fine sands with positive correlation of the abundance and size of shell fragments with the coarseness of the mean seabed sediment grain size (Figure 37). Shell input is patchy across all ranges of water depth but there is no indication of systematic variations of graphic mean grain size in the total sediment sample with the subtle changes of water depth (Figure 38).

4. Interpretation

The interpretations of data summarized above reinforce the observations previously published on bank structure and the maintenance of sandbank function in non-storm conditions (Figures 13-16). Insights on bank function in non-storm conditions are:

a. Regionally consistent patterns of fining of the seabed sands correlate with position across the banks and net sand transport from west to east across the Norfolk Banks (Figure 41). The directions of net sand transport offshore are in overall agreement with the directions modelled for the tidal depth-averaged currents (Figure 12). Although similar patterns have been inferred from interpretation of mean grain size data derived from Haisboro Sand (McCave and Langbourne, 1982), they have not previously been *regionally* verified across the Norfolk Banks because of the lack of suitable seabed sample data.

b. The patterns summarised in a) above occur in the areas with the strongest near-bottom currents. Those banks with data not appearing to fit with the process models summarized above are Race Bank, Cromer Knoll, northern Haddock Bank, northern Swarte Bank, Viking Banks and the Indefatigable Banks. With the exception of Race Bank, these occur in areas of relatively weak tidal streams.

c. The processes for producing the patterns of east-fining across the Norfolk Banks are interpreted as being caused by an overall decrease in near-bottom current strengths across the banks, progressive mixing of individual sediment populations, transport of fine-grained sand across the banks and clockwise along-slope net sediment transport around the banks (Figure 15).

d. Patterns of mean grain size values and gradients that appear to abruptly shift across the bank crests can be interpreted as being due to mixing of two sediment populations derived from superimposed processes. One is the offshore-directed cross-bank net sand transport associated with sands fining to the NE with position across the bank. The other is interpreted as being due to decoupling across the crests associated with the opposing net sand transport directions on the adjacent bank flanks. Thus mean grain size varies systematically across bank and along-bank with opposing along-bank trends on adjacent flanks. The results of 2-process superimposition on variations of mean grain size were theoretically predictable from the generic model compiled for bank function (Figure 15). Until now a model for interaction between along- and across-bank processes has not been verified from seabed sample data.

e. The proposed qualitative but functional model is shown schematically for data extracted from Ower Bank B (Figure 42). The possible attributes of the model are:

   Trends in mean grain size may be used to map discrete and process-driven functional segments within the banks.

The model predicts that in cells where the process of clockwise sediment circulation predominates, the finest sediments on the banks are likely to be found on the SE flanks and the coarsest sediments on the SW flanks.

Across- and along-bank processes combine to deposit relatively fine sediments on the NE flanks. This has implications for predicting the effects of dispersion or accumulation of pollution from particles with hydraulic equivalents comparable to the range of particle sizes on the banks.

f. Switches from positive to negative correlation of mean grain size with position from west to east (Figure 41) are interpreted to occur with net sand transport towards the crest and relatively stable accumulation of sands on and around the bank crest.

g. Significant shifts of mean grain size value and gradient with position across a flank are predicted to occur with differences of sediment source, for example, because of mean grain size variations with position across superimposed bedforms or with changes of composition of source areas if there is a strong contribution from the troughs.

h. Leakage of sand is inferred by the trends of decreasing grain size on bedforms crests and the bedform facing directions across the trough joining the (northern) tail of Broken Bank to a small un-named bank west of Swarte Bank (section 3.1.10). The mean grain size of the crest sand is typical of that observed on the SW flanks of the Norfolk Banks. Bedform facing directions also indicate possible net sand leakage to the north between Well Bank and Broken Bank (Figure 41). Bank geomorphology also indicates that sand is leaking between Ower Bank, Inner Bank and Well Bank (frontispiece). These interpretations from the mean grain size data are important as they are consistent with previous inferences that net offshore sand transport is occurring across the troughs separating the Norfolk Banks.

i. The data showing the overall coarser seabed sediments from Indefatigable Bank are consistent with an interpretation for their origin as relict sediments originating from profound long-term erosion of seabed in that area (section 3.1.3). These banks appear to be undergoing a process of permanent natural destruction.

Interpretations from the Dogger Bank data are:

a. The height of the Dogger Bank above the surrounding seabed is not indicative of the thickness of underlying sands, rather it records the thickness of sediments that were deposited at a former terrestrial ice margin more than 10,000 years ago. The bulk of the Dogger Bank is therefore interpreted as stable and immobile over the long term.

b. The fine sands on the shoal banks show no correlation of the mean grain size with position across the bank plateau except where areas with seabed scour, commonly hollows up to 2m or depth, feature with coarse sandy, gravelly and hard cohesive sediments. The seabed sediments in the scour areas are interpreted as relict and likely to have been eroded or exposed during storm conditions.

c. In the areas unaffected by seabed scour the seabed is predominantly fine sand and mobile bedforms were not acoustically resolved in the areas of survey. The external preservation of the scour on the Dogger Banks is attributed to their lack of infill by mobile sand.

d. Extensive areas of seabed scour occur in sediments that are difficult to erode and over a similar range of water depths to those associated with the Norfolk Banks. The inference from these observations and their interpretation is that extensive storm-induced scouring has probably affected the Norfolk Banks but because they are characterised by mobile sand, the evidence for the scour is not preserved. The relative ease of erosion of fine and uncohesive sediments on the Norfolk Banks indicates that the effects of storm-induced scour will be far more extensive and profound on the Norfolk Banks than for energy-equivalent events on the Dogger Bank.

5. Conclusions

a. This research provides a factual basis for explaining seabed sand-size sediment grain size variations under non-storm conditions in the large area covered by the Smith's Knoll, Leman, Ower, Inner, Well, Broken, Swarte and southern Haddock Banks. The tentative model is for segments with cells of high positive correlation between variations of medium to fine sand mean grain size with position on the banks.

b. A significant gap in our knowledge about the sandbanks is the variations to the size and continuity of the segments of systematic sediment grain size variations under non-storm conditions. These are important to understand as the early indications are that they could form the basis for quantitative studies of sand bank function.

c. There is no correlation of mean sand grain size with position across the Dogger Bank. The coarse sands and gravels that occur in the areas affected by seabed scour probably do not reflect non-storm hydrodynamic conditions.

d. Although they form a small proportion of the bulk of the Norfolk Banks, the superimposed bedforms are an important component of the variation of the morphology of the seabed. A significant gap in the knowledge is the contributions of the small to very large-scale transverse bedforms to the overall trends of grain size variation within the medium to fine sand size classes across the Norfolk Banks.

e. The pathways for bedload transport across the Smith's Knoll, Leman, Ower, Inner, Well, Broken, Swarte and southern Haddock Banks are interpreted as being coupled across the troughs that separate them. The significance of this interpretation is that the disturbances to any one of the banks will be reflected more or less on the adjacent troughs and banks.

f. The geological perspectives and interpretations of the new data confirm the pre-existing generic models indicating that the named sand banks are mobile and migrating as semi-closed sand sinks to the east and to the north. The heads of the banks influence the positions of the bank tails, but their rates of movement are not known.

g. A preposition based on interpretations of bank structure from the few available high quality sub-seabed profiles is that the banks are segmented into internal aggradational and progradational styles. A significant gap in the knowledge on integral bank function arises from the lack of high quality data to systematically map the segmentation of internal bank structure and to test if it may be related to segmented bank seabed function.

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7. Glossary of terms

Astronomical tide	The tide levels and character which would result from the gravitational effects of the earth sun and moon without any atmospheric influences
Bed	The bottom of any body of water, e.g. seabed
Bedforms	Features on the seabed (eg sand waves, ripples) resulting from the movement of sediment over it, from seabed erosion, from deposition of stable sediment
Bedload	Sediment particles that travel near or on the bed
Bed shear stress	The way in which waves and currents transfer energy to the seabed
Bioclastic (sediments)	Sediments derived by processes of derivation from biota
Boulder	Rock that is greater than 256mm in diameter, larger than a cobble
Clastic (sediments)	Sediments that have been produced by the processes of weathering and erosion of rocks
Clay	A fine grained sediment with a typical grainsize of less than 0.004mm. Possesses electromagnetic properties which bind the grains together to give bulk strength or cohesion
Coast	A strip of land of indefinite length and width that extends from the seashore inland to the first major change in terrain features
Coastline	The line that forms the boundary between the coast and the shore
Cobble	Rounded rocks, ranging in diameter from ~64-256mm
Cohesive	Said of soil that has relatively high shear strength when air-dried, and high cohesion when wet, e.g. mud.
Cohesive sediment	Sediment containing a significant proportion of clays, the electromagnetic properties of which cause the particles to bind together, eg. muds in SEA2
Comet marks	Seabed features that form in the lee of structures such as wrecks. May result from sediment scour or accumulation
Continental shelf	That part of the continental margin that is between the shoreline and the continental slope (or, when there is not a noticeable break with the continental slope, a depth of 200m). It is characterised by its very gentle slope of 0.1°

Contour line	A line connecting on the land or under the sea which have equal elevation. See also isobath
Crest	Highest point on a bedform
Crust	The outmost layer or shell of the Earth, defined according to various criteria, including seismic velocity, density and composition.
Current	Flow of water generated by a variety of forcing mechanisms (eg waves, tides, winds, surges etc)
Datum	Any position or element in relation to which, others are determined
Deep water	Water too deep for waves to be affected by the seabed (typically taken as half the wavelength)
Depth	Vertical distance from still water level or other specified datum, most commonly lowest astronomical tide, to the seabed
Diamicton	A general term for an unsorted sediment
Diapir	A dome or anticlinal fold in which the overlying rocks have been ruptured and penetrated by the squeezing-out of plastic core material. Diapirs in sedimentary strata usually contain cores of predominantly salt or shale
Direction of current	Direction toward which current is flowing
Direction of waves	Direction from which waves are coming
Direction of wind	Direction from which wind is blowing
Diurnal	Having a period of a tidal day 24.84 hours
Ebb tide	Period of time during which the tidal level is falling
Erosion	Wearing away of the land or seabed by natural forces (wind, waves, currents, chemical weathering)
Eustatic	Pertaining to worldwide changes of sea level that affect all the oceans. Eustatic changes may have various causes, but the changes dominant in the last few million years were caused by additions of water to, or removal of water from, the continental icecaps.
Extreme	The value expected to be exceeded in a given (long) period of time
Facies	The sum of features such as sedimentary rock type, mineral content, sedimentary structures, bedding characteristics, fossil content etc which characterise sediment as having been deposited in a given environment
Fetch	Distance over which the wind acts to produce waves
Flood tide	The period of time when tide levels are rising

Fluvial	Of or pertaining to a river or rivers.
Flux	Rate of mass transfer measured as rate at which the volume or the dry weight of sediment crosses a metre length per unit time. May be divided into components eg. sediment classes (sizes, types), drivers of velocity (tides, winds, waves, surges) and fluid setting (bedload or suspended load)
Geomorphology	The investigation of the history of geologic changes through the interpretation of topographic forms
Geotechnical	Pertaining to the broad field of geotechnics.
GIS	Geographical Information System – A system of spatially referencing information, including computer programs that acquire, store, manipulate, analyse and display spatial data
Glacigenic	Originating from a glacier or an ice sheet
Gravel	Loose, rounded fragments of rock larger than sand but smaller than cobbles. Material larger than 2mm (Wentworth scale used in sedimentology) or 5mm (used in dredging industry)
High water	Maximum level reached by the rising tide
Hydraulic	Pertaining to a fluid in motion, or to movement or action caused by water.
Hydrodynamic	The aspect of hydromechanics that deals with forces that produce motion
Inshore	Areas where waves are transformed by interactions with the seabed
Intercalated	Said of layered material that exists or is introduced between layers of a different character; or relatively thin strata of one kind of material that alternate with thicker strata of some other kind, such as beds of shale that are intercalated in a body of sandstone.
Isobath	Lines connecting points of equal water depth. Seabed contours.
Littoral	Pertaining to the benthic submarine environment or depth zone between high water and low water, also pertaining to the organisms of that environment.
Longshore	Parallel and close to the shoreline

Longshore current	A current located in the surface zone, moving generally parallel to the shoreline that is generated by waves breaking at an angle with the shoreline
Longshore drift	The movement of sediment approximately parallel to the shoreline
Low tide	See low water
Low water	The minimum height reached by the falling tide
Mean sea level	The average level of the sea over a period of approximately 12 months, taking account of all tidal effects but excluding surge events
Mean water level	The average level of the water over the time period for which the level is determined
Megaripples	Out dated term for bedforms of wavelength approximately 0.6 – 10m and height + 0.1 – 1m. These features are smaller than sandwaves but larger than ripples
Metadata	Text that describes the key points relating to e.g. a particular field dataset, paper or report
Mineral	A naturally occurring inorganic crystalline solid that has a definite chemical composition and possesses characteristic physical properties
Morphology	(a) The shape of the Earth's surface geomorphology (b) The external structure, form and arrangement of rocks in relations to the development of landforms.
Mud	An unconsolidated sediment consisting of clay and/or silt, together with material of other dimensions (such as sand), mixed with water without connotation as to composition.
Neap tide	A tide that occurs every 14.8days at or near the time of half moon and which displays the least positive and negative deviation from mean sea level
Near shore	The zone which extends from the swash zone to the position marking the start of the offshore zone (~20m)
Numerical modelling	Refers to the analysis of coastal processes using computational models
Offshore	The zone beyond the nearshore zone where wave induced sediment motion effectively ceases and where the influence of the seabed on wave action has become small in comparison with the effects of wind
Onshore	A direction landward from the sea

Outwash	Stratified detritus (chiefly sand and g ravel) removed or “washed out” from a glacier by meltwater streams and deposited in front or beyond the end moraine or the margin of an active glacier. The coarser material is deposited nearer the ice.
Overburden	The upper part of a sedimentary deposit, compressing and consolidating the material below.
Particle size	In dealing with sediments and sedimentary rocks, it is necessary that precise dimensions should be applied to such terms as clay, sand etc. Numerous scales have been developed and the Wentworth scale is widely accepted as an international standard
Permanent current	A current that runs continuously and is independent of the tides or other forcing mechanisms. Permanent currents include large scale ocean circulatory flows and the freshwater discharge from rivers
Quaternary	The youngest geological period that includes the present time
Residual water level	The components of water level not attributable to astronomical effects
Ripple	Sediment bedform produced by fluid movement over sediments. Oscillatory currents produce symmetric ripples whereas a well defined current direction produces asymmetric ripples. The crest line of a ripple may be straight or sinuous. The characteristic features of these bedforms depend upon current velocity, particle size and the persistence of current direction. Ripples usually have low amplitudes (~ <0.06-0.1m)
Rocks	An aggregate of one or more minerals that falls into one of three categories: Igneous rock that is formed from molten material, sedimentary rock that results from the consolidation of loose sediment that has accumulated in layers and metamorphic rock that has formed from pre-existing rock as a result of heat or pressure
Sand	Sediment particles, mainly of quartz with a diameter of between 0.062mm and 2mm (Wentworth scale), or less than 5mm (dredging industry). Sand is generally classified as fine, medium or coarse
Sandwaves	Outdated term for an asymmetric bedformed with heights of up to 1/3 water depth and wavelengths > ripples (approx. 0.06-0.1m). Sandwaves may be used to give an indication of the predominant direction of sediment transport. These features are sometimes known to migrate at speeds of several km/year
Sediment	Particulate matter derived from rock, minerals or bioclastic matter
Sediment flux	The flow of sediment in suspension and as bedload across the seabed
Sediment sink	A point or area at which sediment is lost from a coastal cell or transport pathway, such as an estuary or a deep channel in the seabed

Sediment source	A point or area from which sediment arises such as an eroding cliff, seabed itself, or river mouth
Sediment transport	The movement of a mass of sedimentary material by the forces of currents and waves. The sediment in motion can comprise fine material (silts and muds), sands and gravels. **Potential** sediment transport is the full amount of sediment that could be expected to move under a given combination of waves and currents, i.e. not supply limited
Sediment transport pathway	The routes along which net sediment movements occur
Semidiurnal	Having a period of approximately one half of a tidal day (12.4 hours). The predominating type of tide throughout the world is semidiurnal with 2 high waters and 2 low waters each day
Significant wave height	The average height of the highest one third of the waves for a given period of time
Silt	Sediment particles with a grain size between 0.004mm and 0.062mm, i.e. coarser than clay but finer than sand
Sink	A depositional area (estuarine, coastal or offshore) into which sediment moves and finally settles out
Slack water	The state of the tidal current when its velocity is virtually zero, particularly when the reversing current changes direction
Sorting	Process of selection and separation of sediment grains according to their grain size (or grain shape, or specific gravity)
Source	An erosional area (cliffs, interidal or subtidal) from which sediment is released for sediment transport
Spring tide	A tide that occurs every 14.8 days at or near the time of the full or new moon and which displays the greatest positive and negative deviation from mean sea level
Stillwater level	The surface of the water if all wave and wind action were to cease
Storm surge	A rise or piling up of water against the shore, produced by strong winds blowing onshore and large atmospheric pressure gradients that force sealevel changes. For coastal flooding storm surge level is most severe when it occurs in conjunction with a high spring tide
Substrates	The substance, or base or the medium, in which an organism lives and grows, or the surface to which a fixed organism is attached; e.g. soil, rocks. This is usually at seabed but can be below seabed.
Surf zone	The nearshore zone along which waves become breakers as they approach the shore

Surge	Changes in water level as a result of meteorological forcing (wind, high or low barametric pressure) causing a difference between the recorded water level and that predicted by harmonic analysis. The surge may be positive or negative
Suspended load	The sediment particles that are light enough in weight to remain lifted indefinitely above the bottom by turbulent flows
Terrestrial	Occurring on the land or continent in a non-marine environment
Tidal current	The alternating horizontal movement of water associated with the rise and fall of the tide
Tide	The periodic rise and fall of the water that results from the gravitational attraction of the moon and sun acting upon the rotating earth
Till	Dominantly unsorted and unstratified drift, generally unconsolidated, deposited directly by and underneath a glacier without subsequent reworking by meltwater, and consisting of a heterogeneous mixture of clay, silt, sand, gravel ranging widely in size and shape.
Topography	The form of the features of the actual surface of the early in a particular region considered collectively
Trough	A long and broad submarine depression with gently sloping sides, or trough of a wave or sedimentary feature
Unconformity	A substantial break or gap in the geologic record where a rock unit is overlain by another that is not next in stratigraphic succession
Unconsolidated	Sediment grains packed in a loose arrangement
Water level	The elevation of a particular point of a body of water above a specific point or surface, averaged over a given period of time
Wave direction	the direction from which the waves are propagating
Wave height	The vertical distance between the crest and the trough
Wavelength	The horizontal distance between consecutive wave crests
Wave period	The time it takes for two successive crests (or troughs) to pass a given point
Wind current	A current created by the action of the wind on the water surface

Figures

The figures illustrated on the following pages have been degraded in quality in order to reduce the size of digital data for the images . High quality images are saved in Corel Draw 10 format in a folder copied to the CD attached to this report. The labels on the images within this folder correspond to the figure numbers in the report.

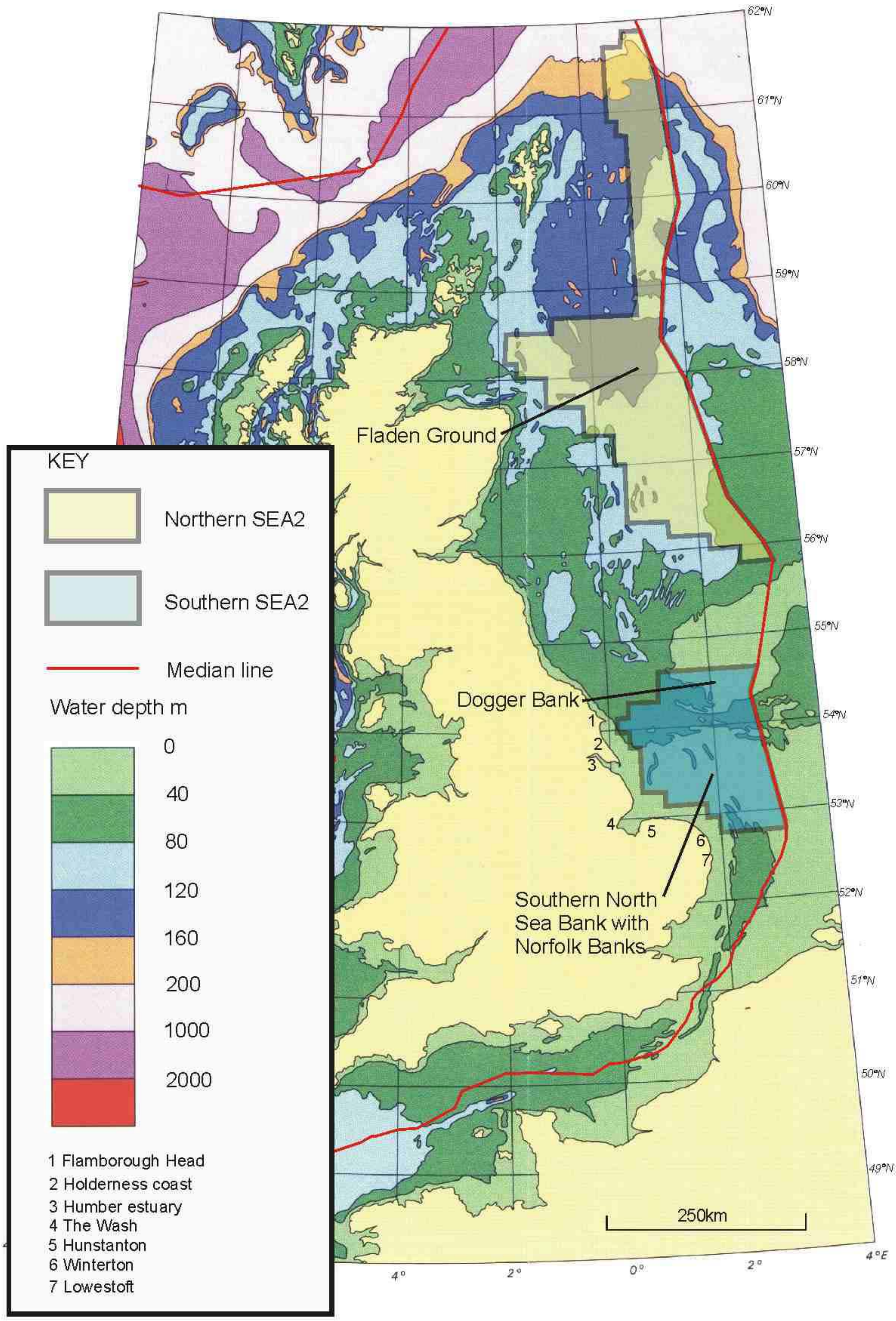


Figure 1 Location and regional seabed geomorphological setting of the northern and southern areas of the SEA2

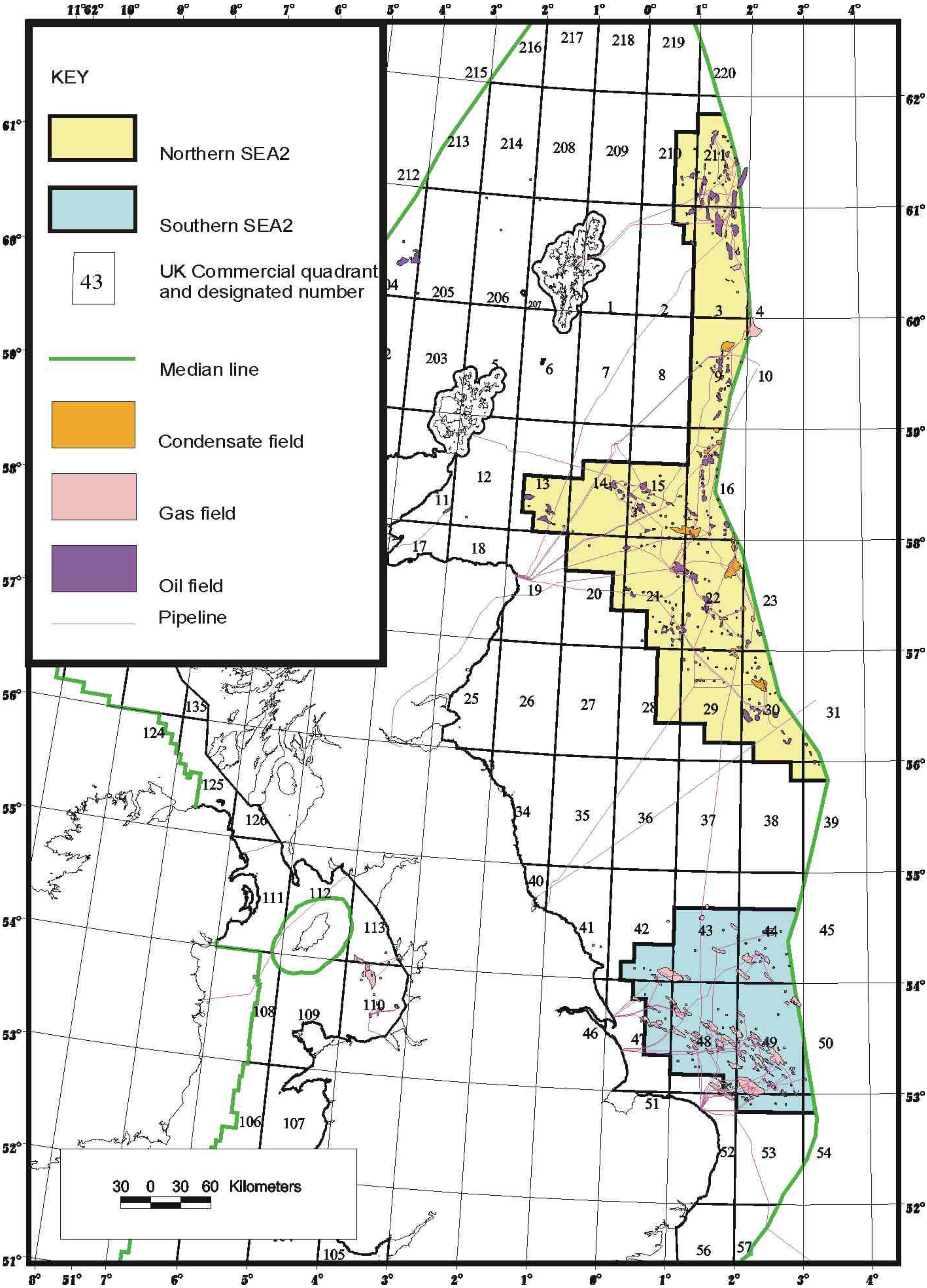


Figure 2 Major oil and gas developed in the northern and southern areas of the SEA2

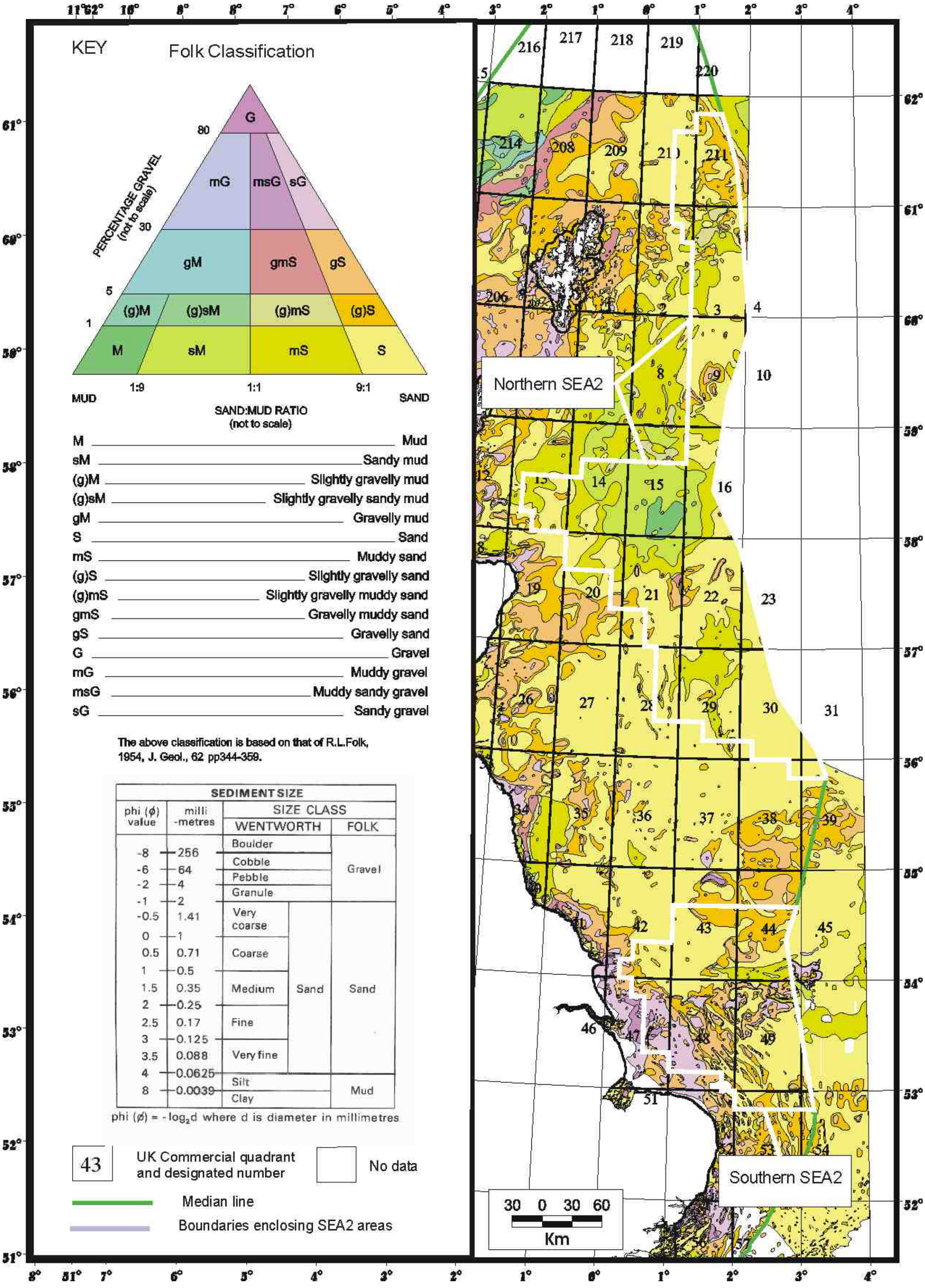


Figure 3 Distribution of seabed sediment classes modelled for northern and southern SEA2 from the BGS regional survey data

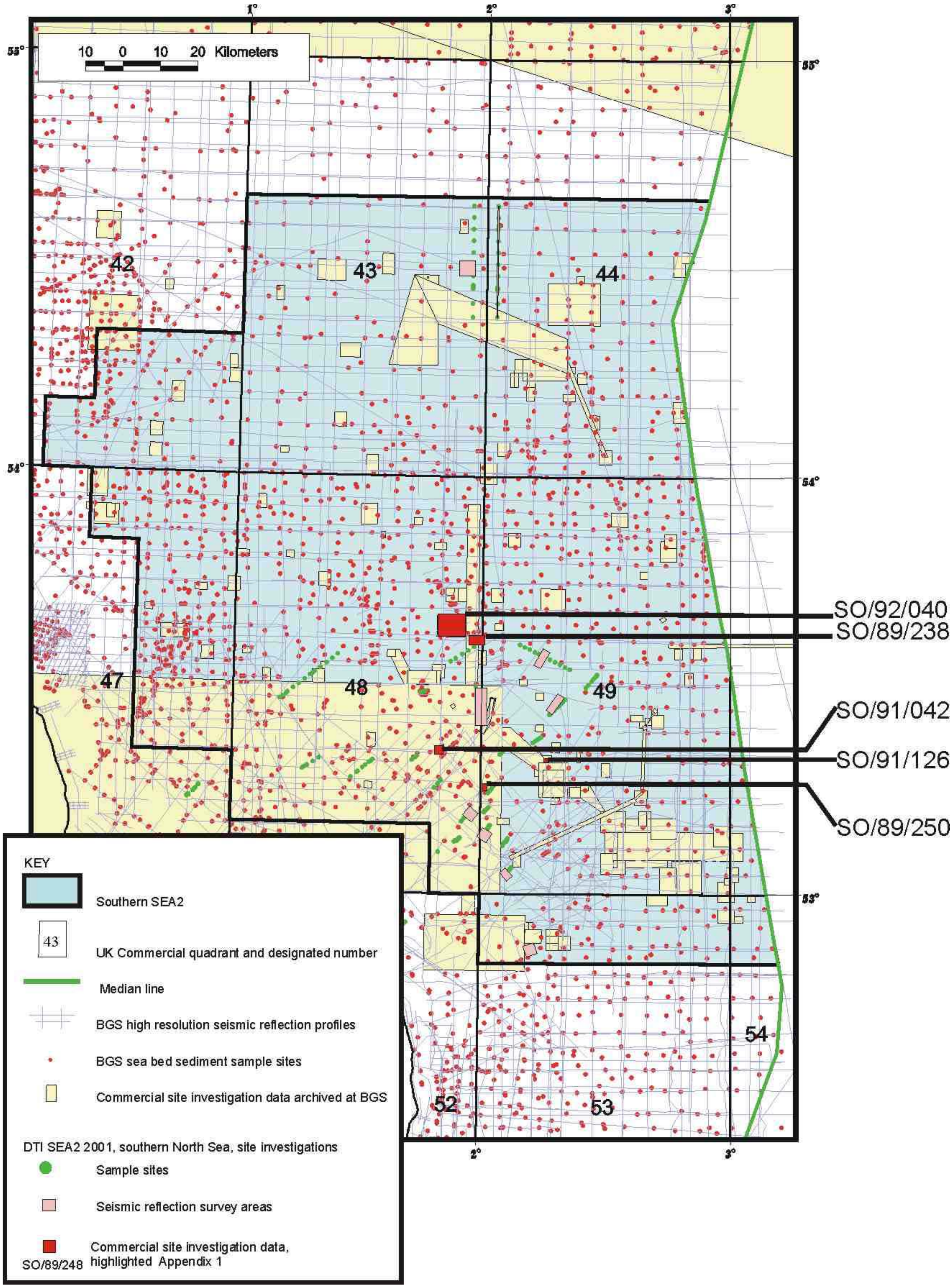


Figure 4. Commercial site investigation and BGS regional survey data, southern SEA2

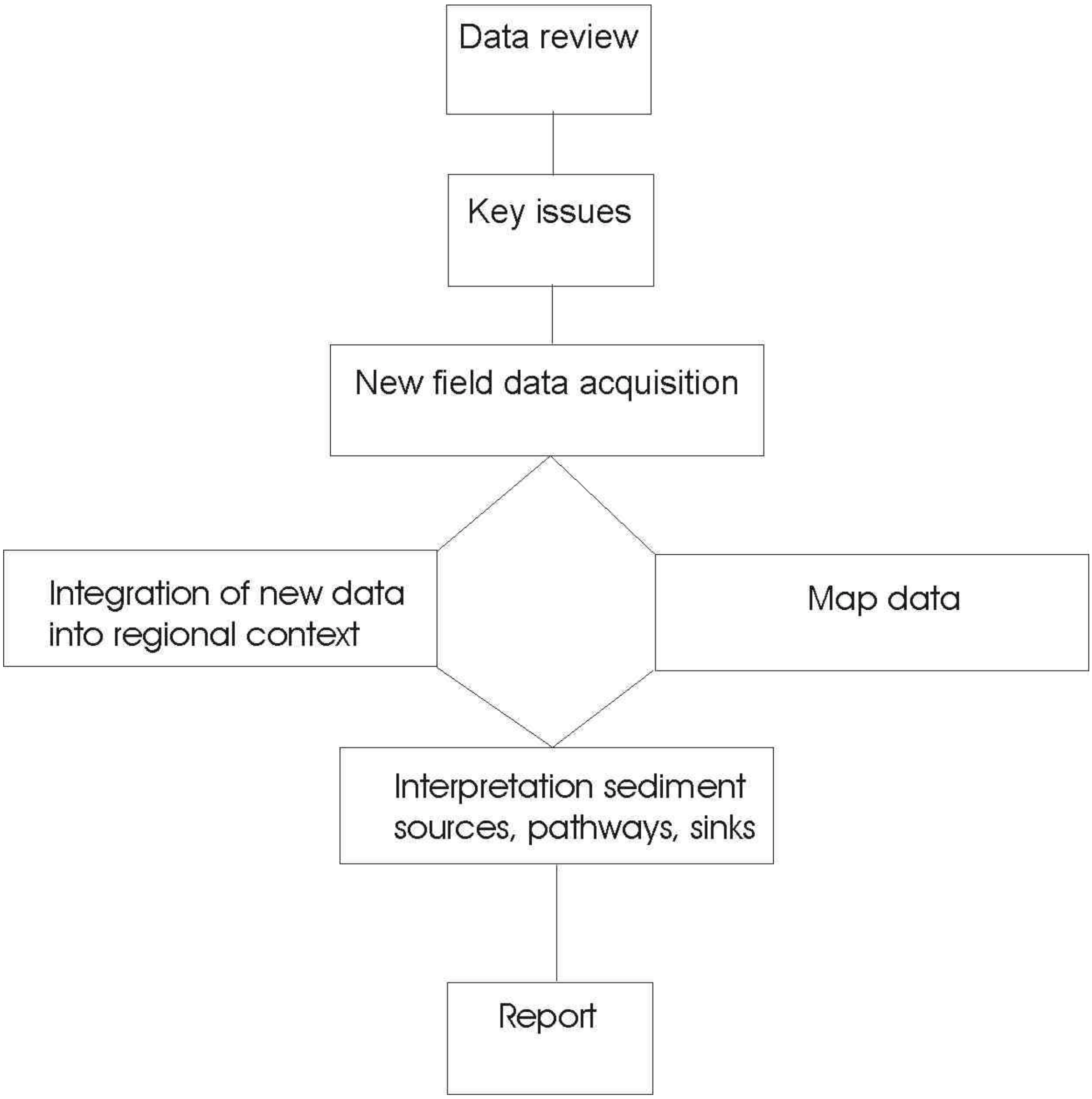


Figure 5 Organisation of work

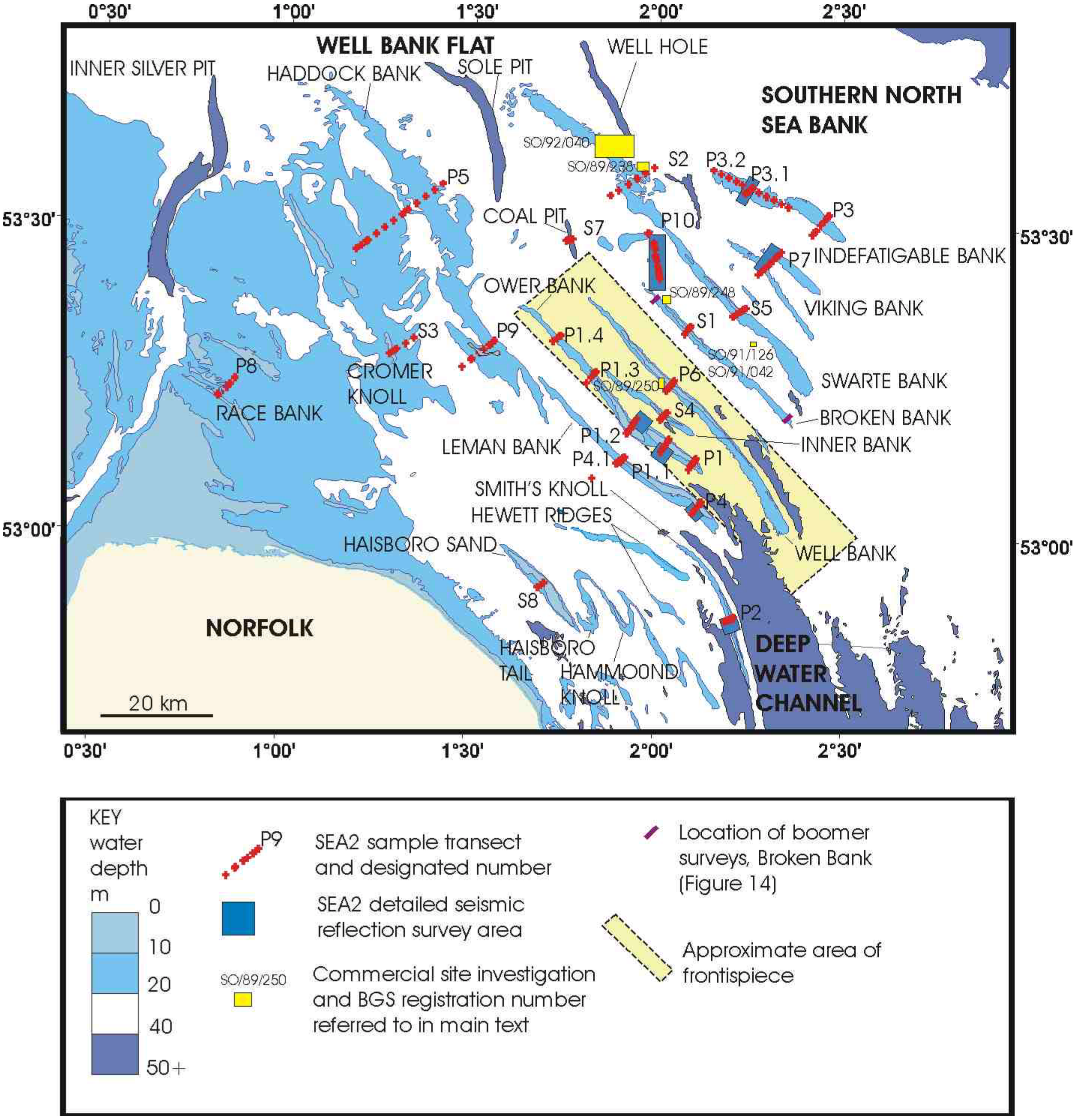


Figure 6 Norfolk Banks: Distribution and seabed geomorphological setting of DTI 2001 survey transects

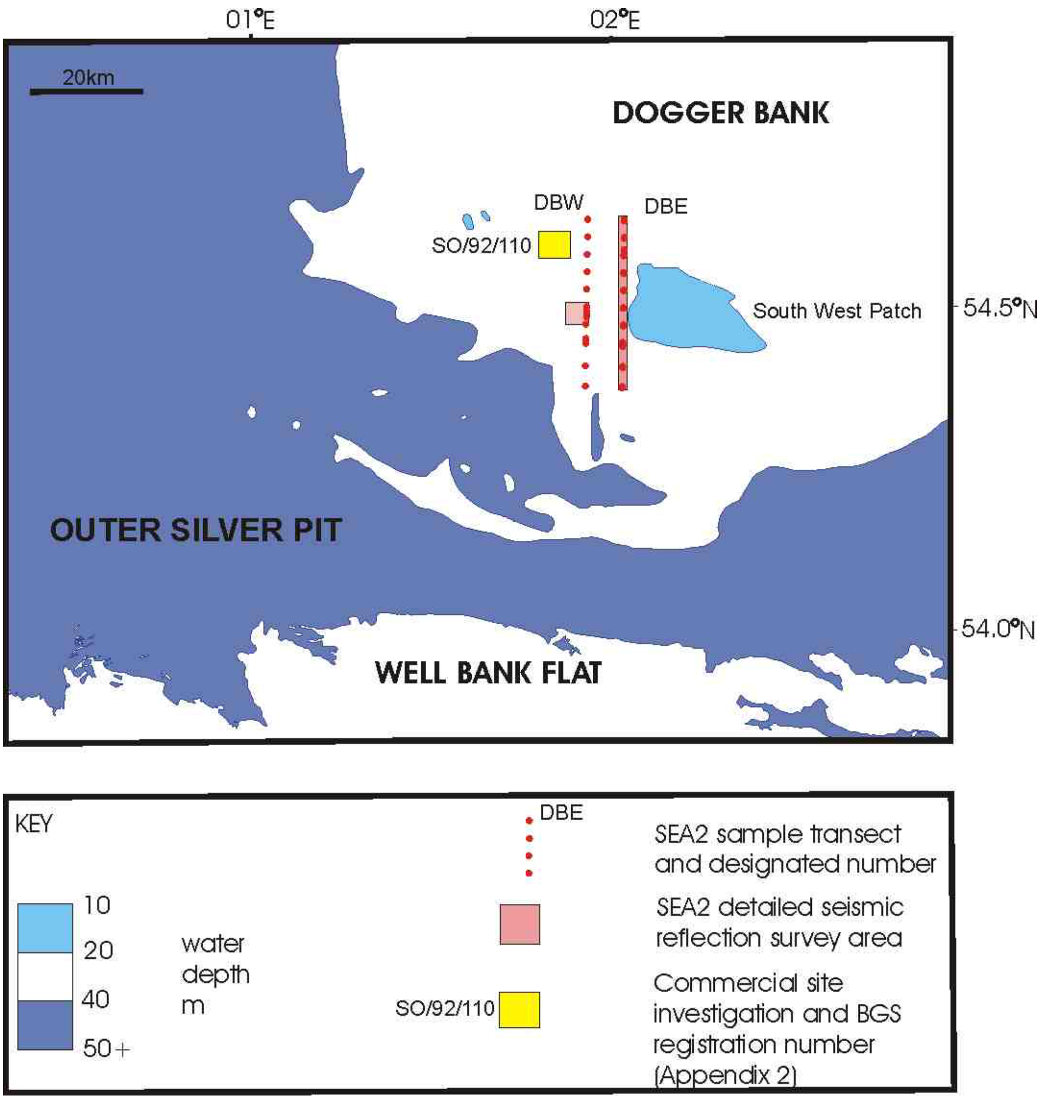


Figure 7 Dogger Bank: Distribution and seabed geomorphological setting of DTI 2001 survey transects

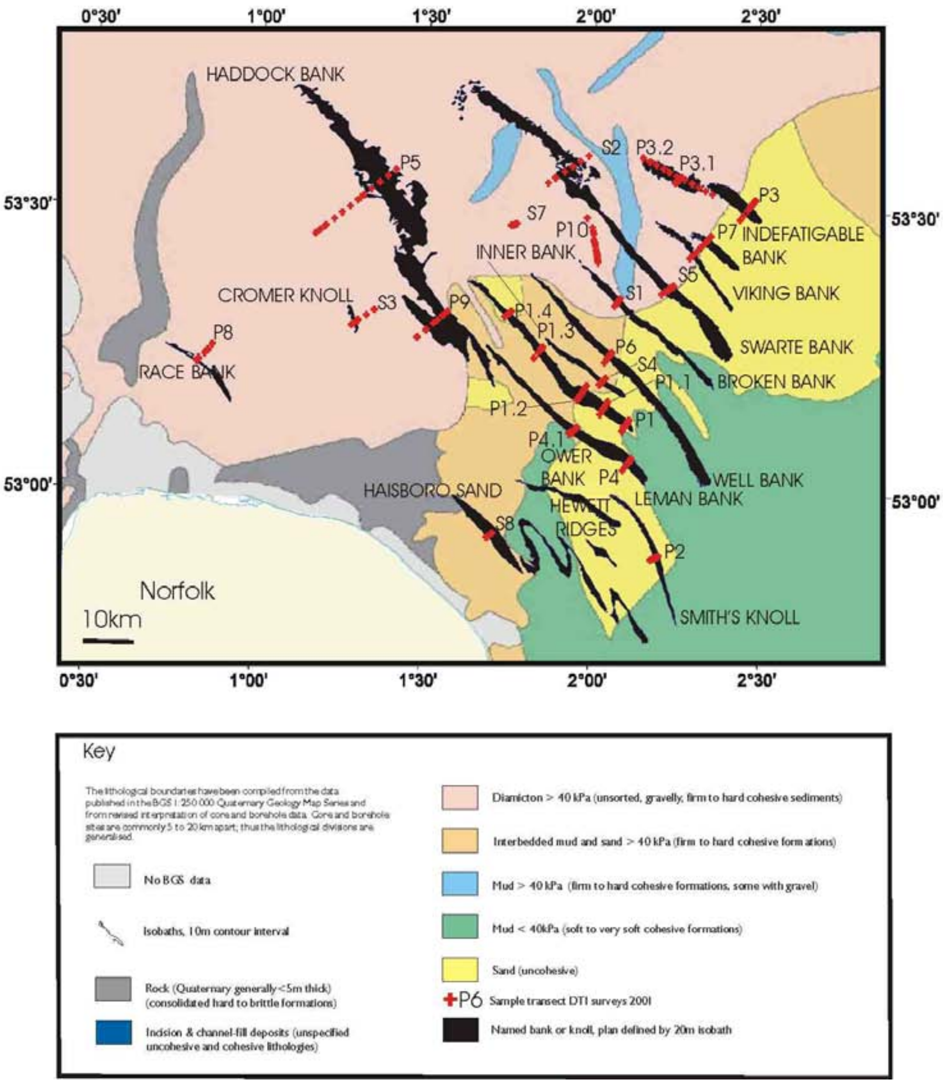


Figure 8 Norfolk Banks: Generalised lithology of formations underlying seabed sediments modelled from the BGS regional survey data

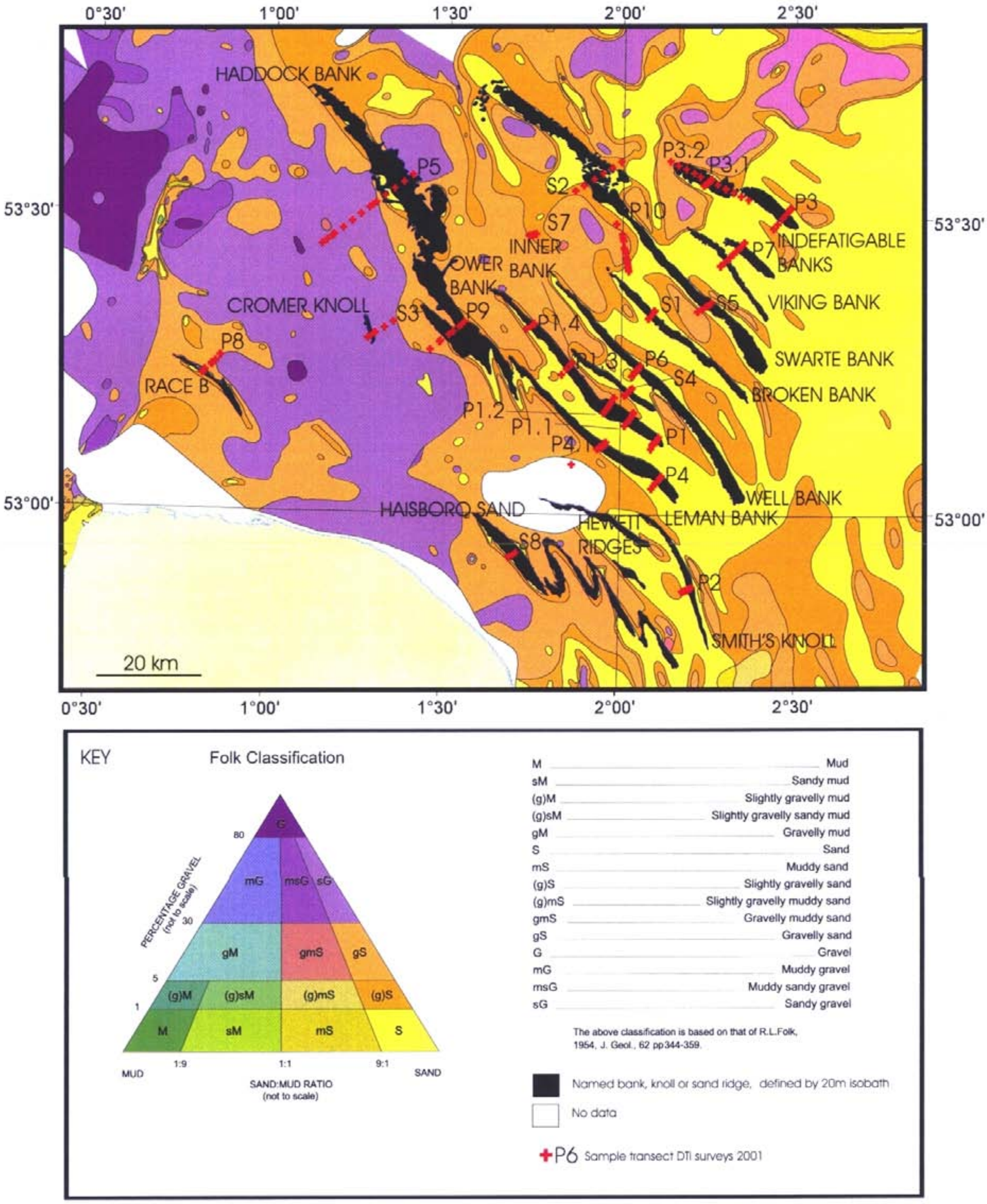


Figure 9 Norfolk Banks: Distribution of seabed sediment classes modelled from the BGS regional survey data

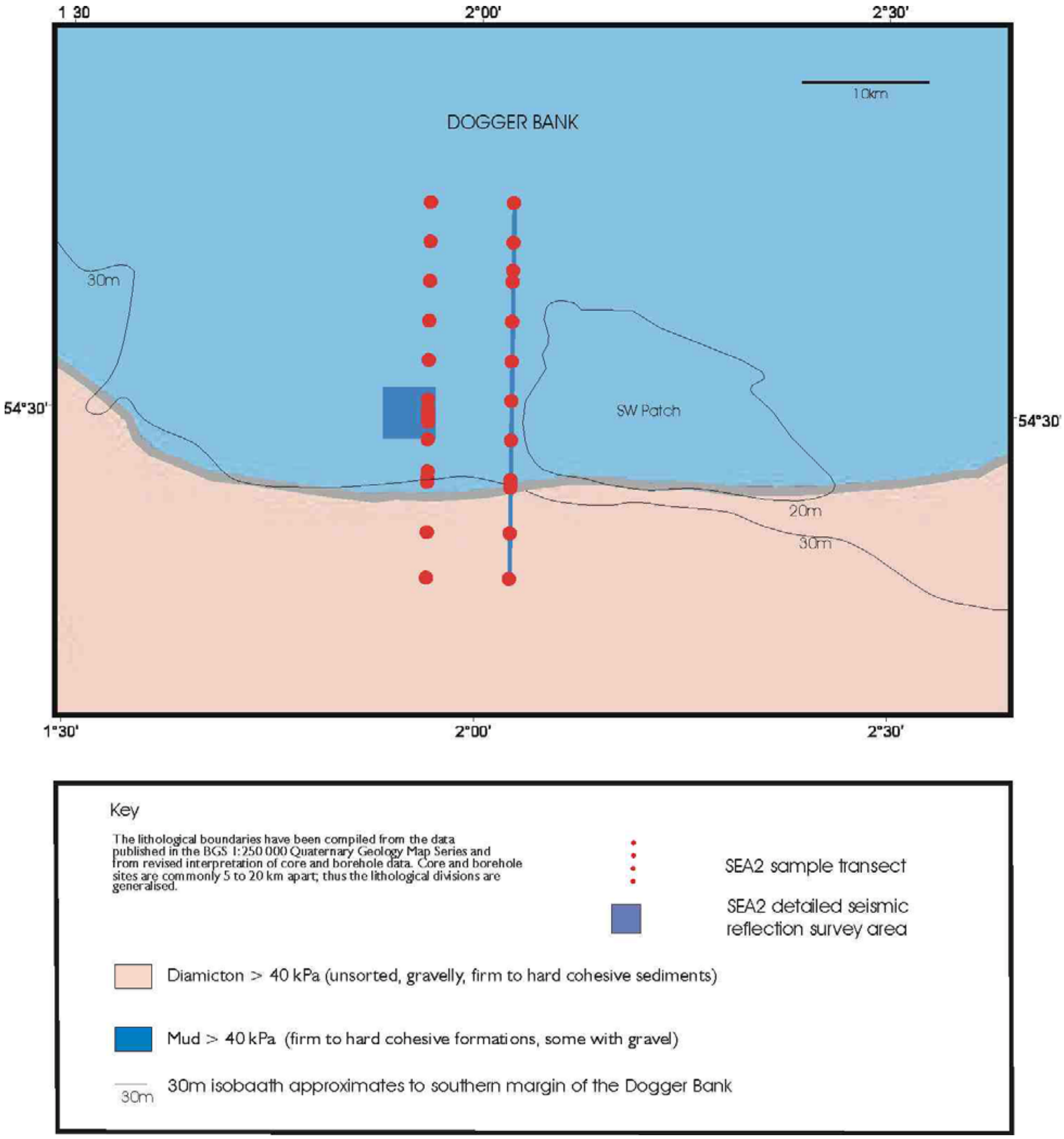
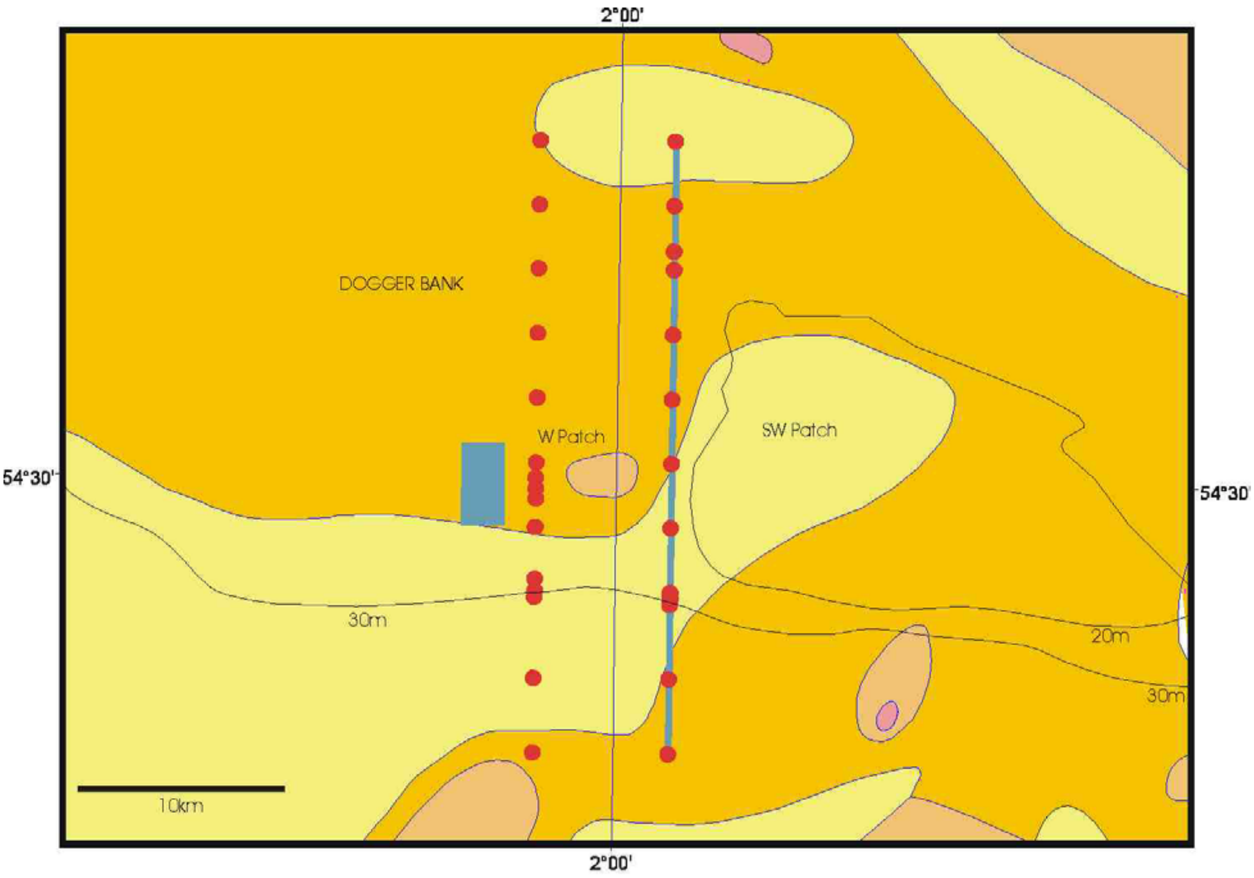


Figure 10 Dogger Bank: Generalised lithology of formations underlying seabed sediments modelled from the BGS regional survey data



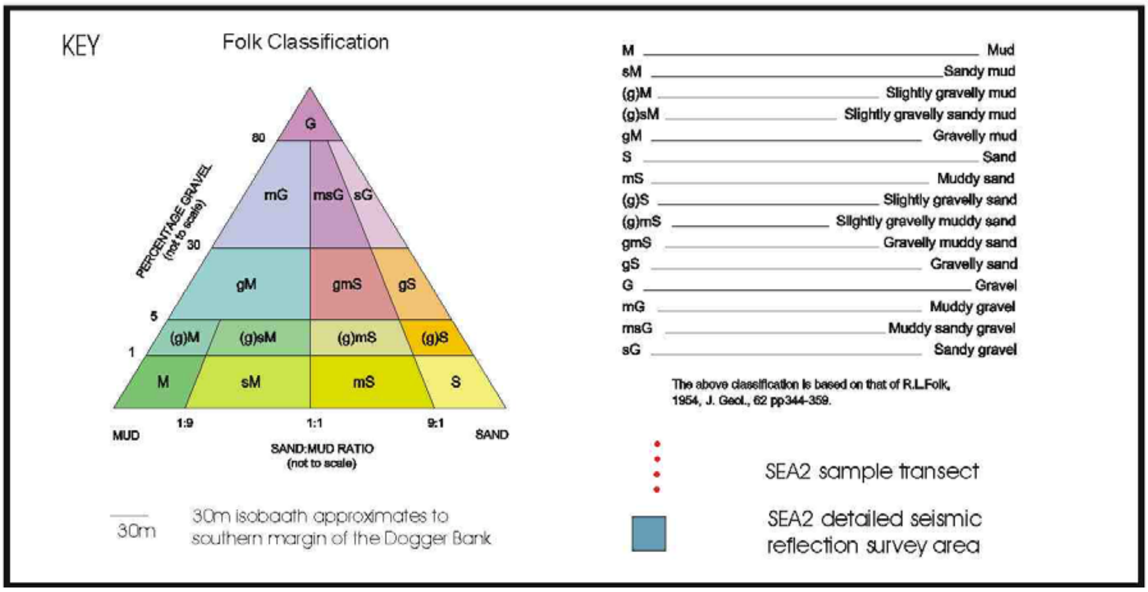


Figure 11 Dogger Bank: Distribution of seabed sediment classes modelled from the BGS regional survey data

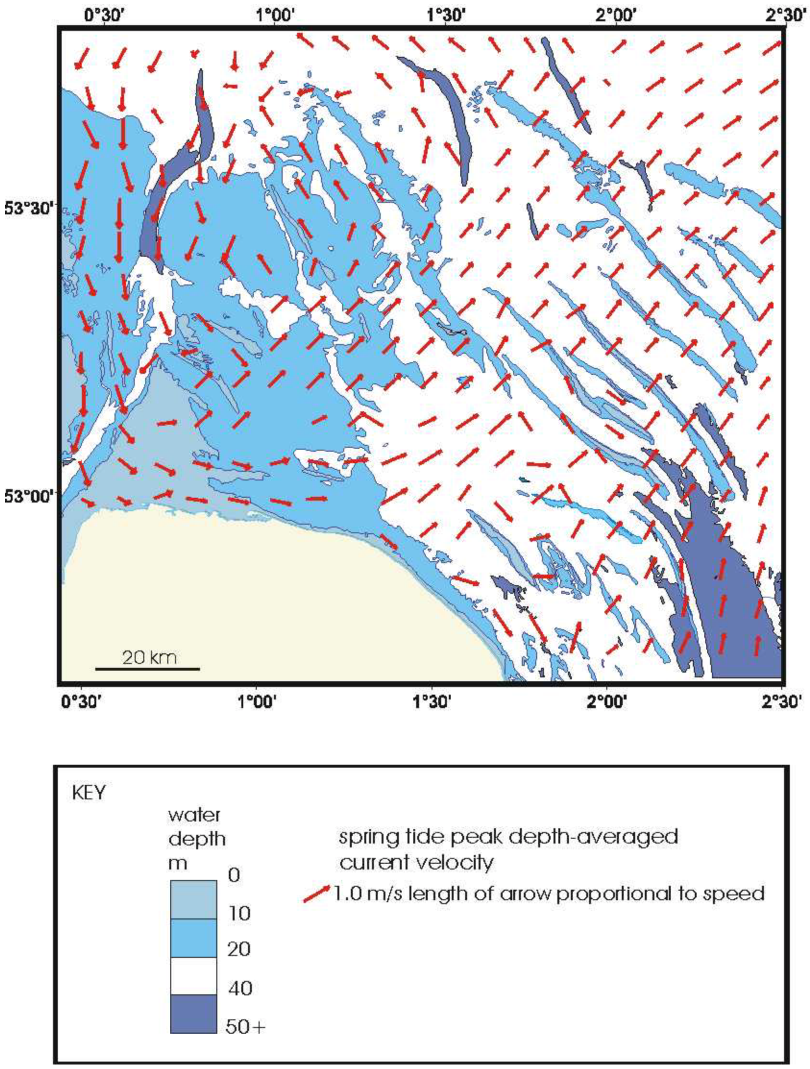


Figure 12 Spring tide peak depth-averaged current velocity

Similar directions of depth averaged currents are found for neap tides and spring tide residual velocities and are more northerly directed for neap tides (after Haskoning and D'Olier, 2002).

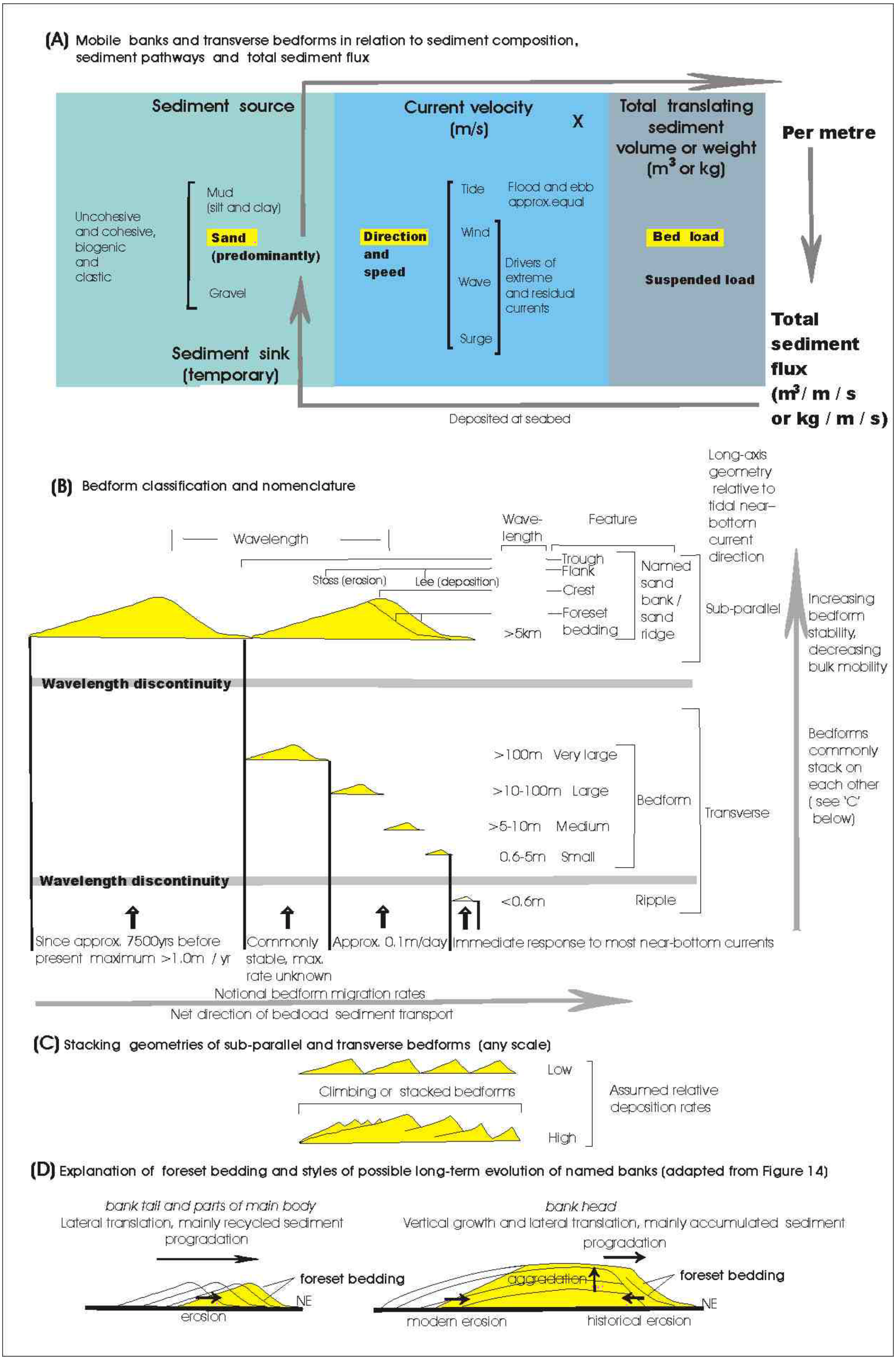


Figure 13 Mobile bedform terminology and processes

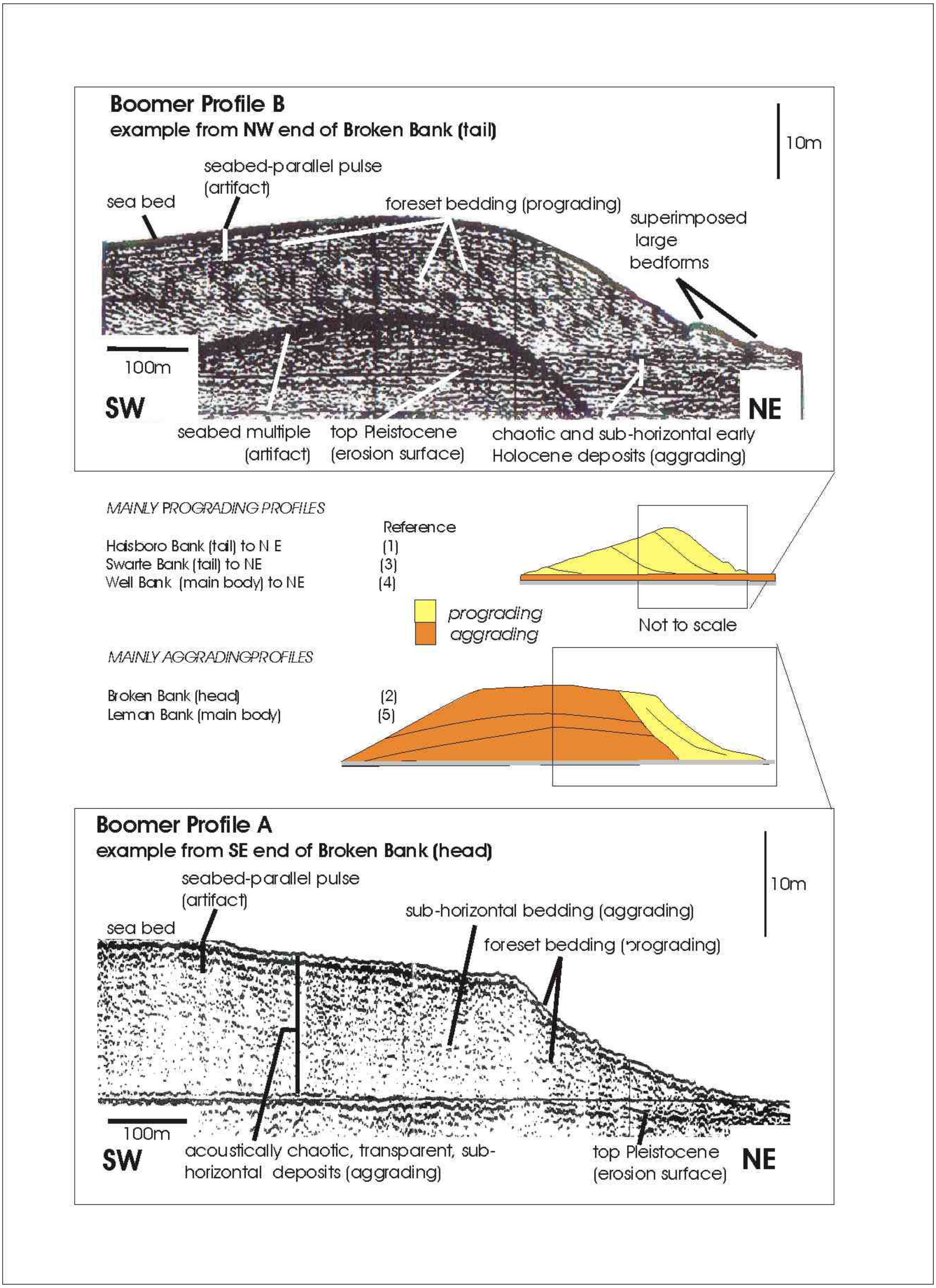


Figure 14 Internal structure Broken Bank

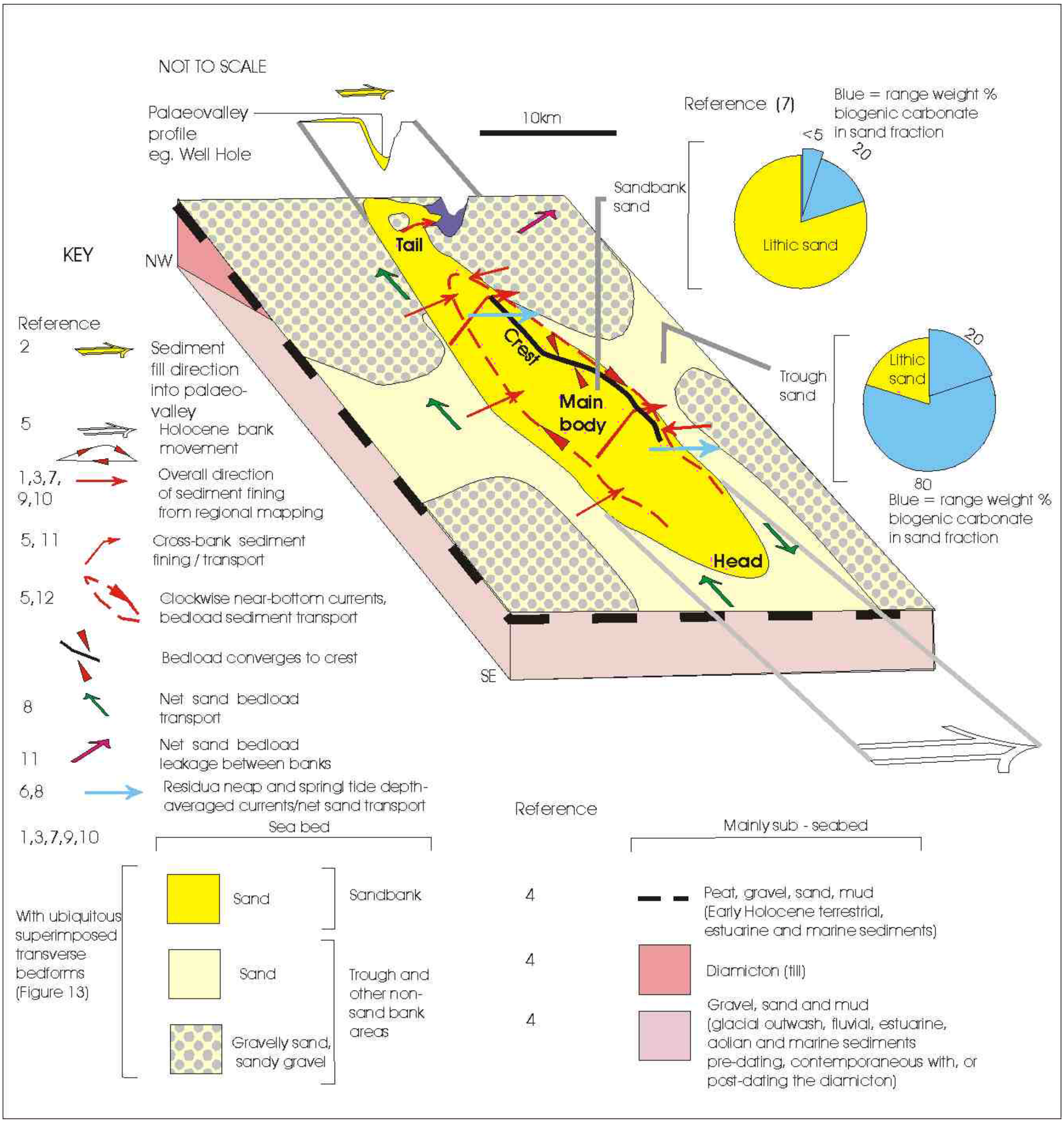


Figure 15 Norfolk Banks: previous work on seabed processes and the stability of the seabed habitat

1. Balson, 1990 2. Balson, 1999 3. Cameron et al, 1984 4. Cameron et al, 1992 5. Caston, 1972 6. Collins et al, 1996 7. Harrison et al, 1987 8. Haskoning and D'Olier, 2002 9. Jeffrey et al, 1988 10. Lott, 1987 11. McCave and Langhourne, 1982 12. Stride, 1988 13. Huthnance, 1973.

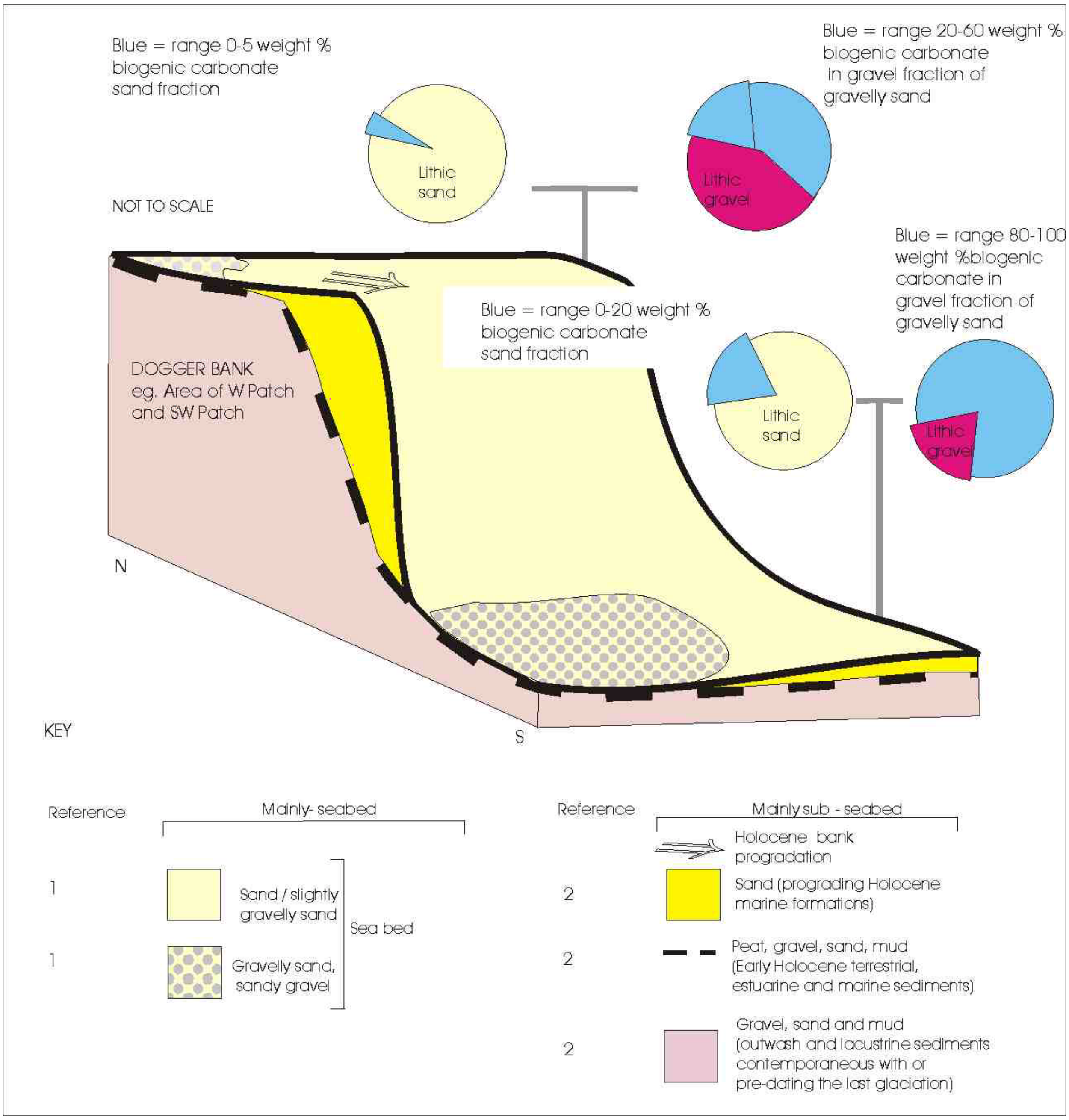


Figure 16 Dogger Bank: previous work on seabed processes and the stability of the seabed habitat

1. Lott, 1987 2. Cameron *et al.* 1992

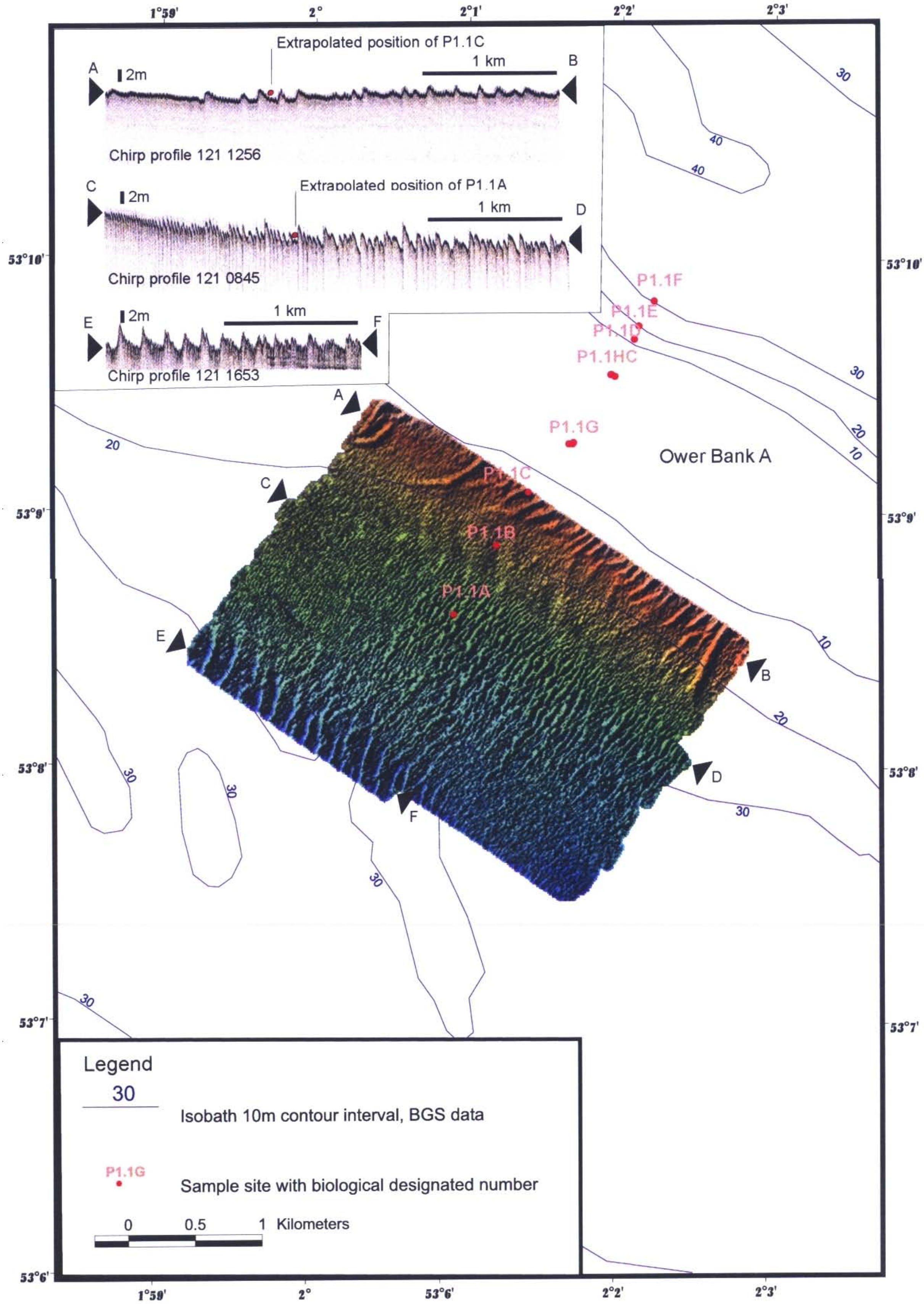


Figure 17 Ower Bank A: seabed geomorphological setting transect P1.1

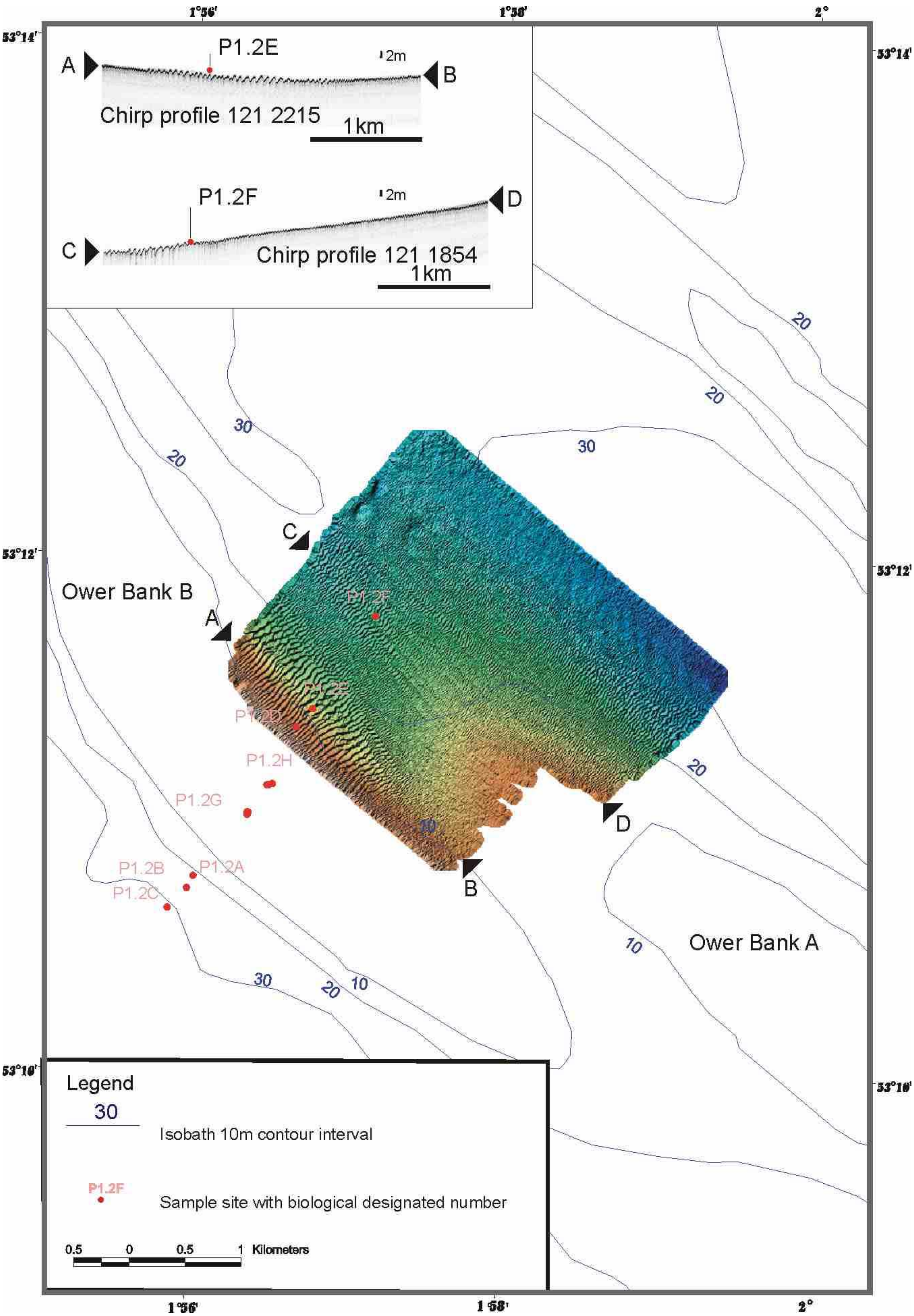


Figure 18 Ower Bank B: seabed geomorphological setting transect P1.2

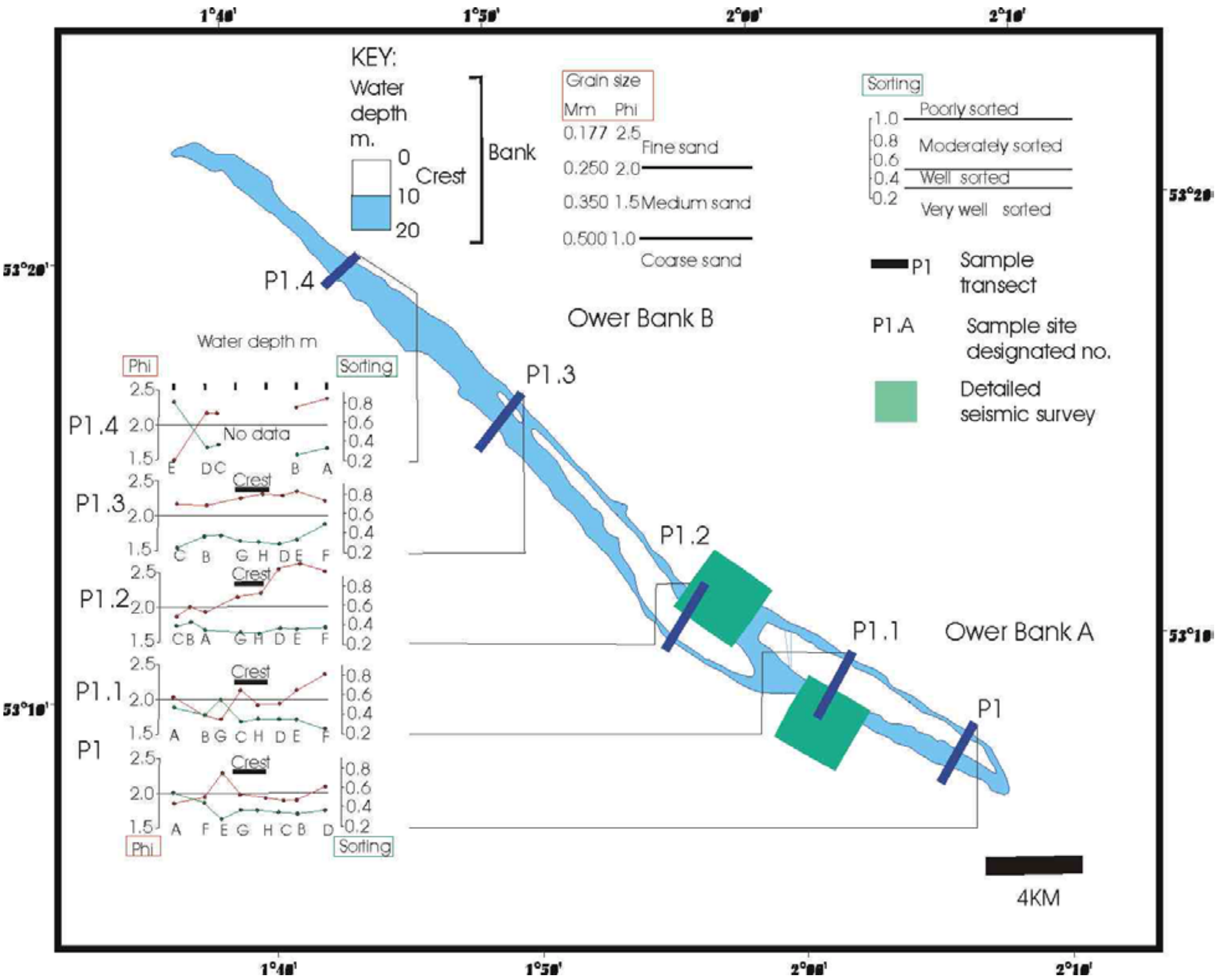


Figure 19 Ower Banks A and B: mean grain size transects P1, P1.1 to P1.4

In Adobe Acrobat point for links with database of seabed photographs and sediment grain size analyses:

P1A P1B P1C P1D P1E P1F P1G P1H
P1.1A P1.1B P1.1C P1.1D P1.1E P1.1F P1.1G P1.1H
P1.2A P1.2B P1.2C P1.2D P1.2E P1.2F P1.2G P1.2H
P1.3A P1.3B P1.3C P1.3D P1.3E P1.3F P1.3G P1.3H
P1.4A P1.4B P1.4C P1.4D P1.4E P1.4F

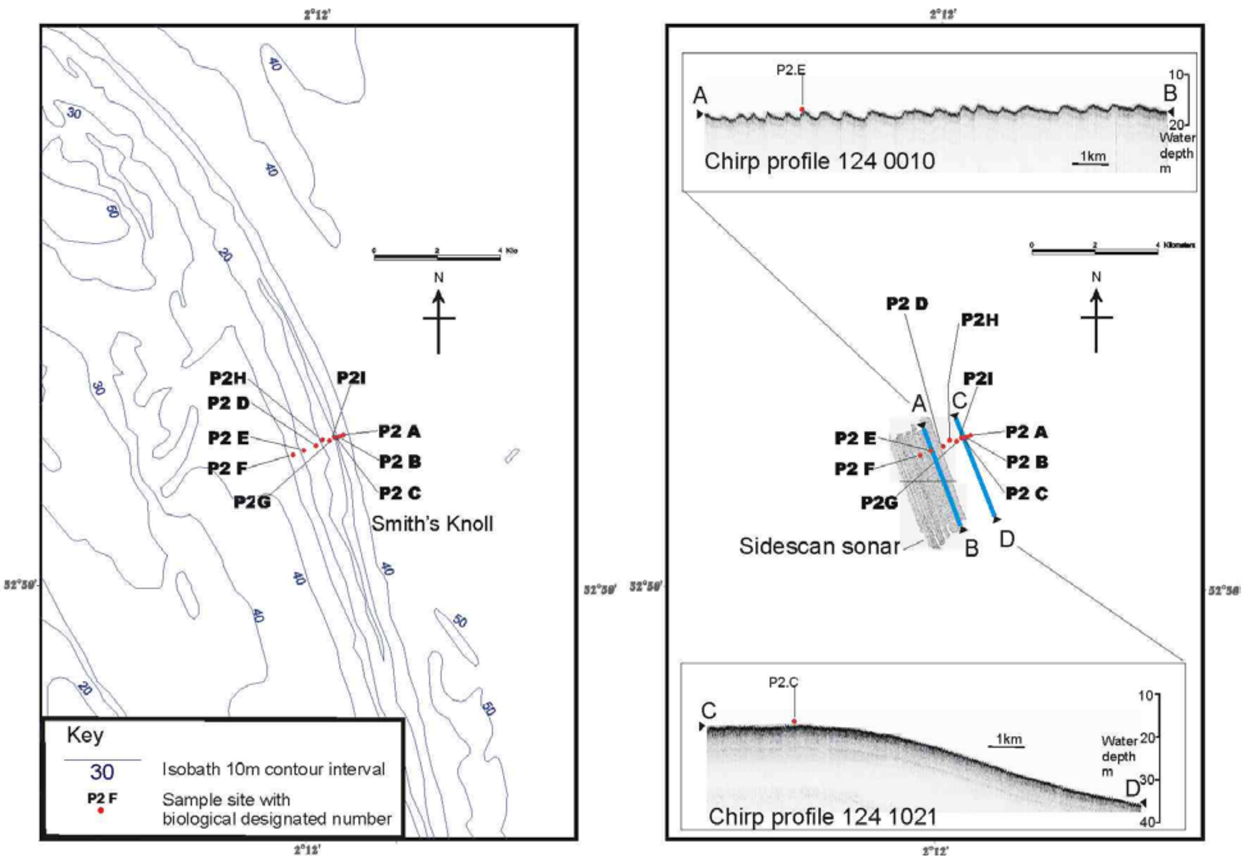


Figure 20 Smiths Knoll: seabedgeomorphological setting and seismic reflection facies transect P2

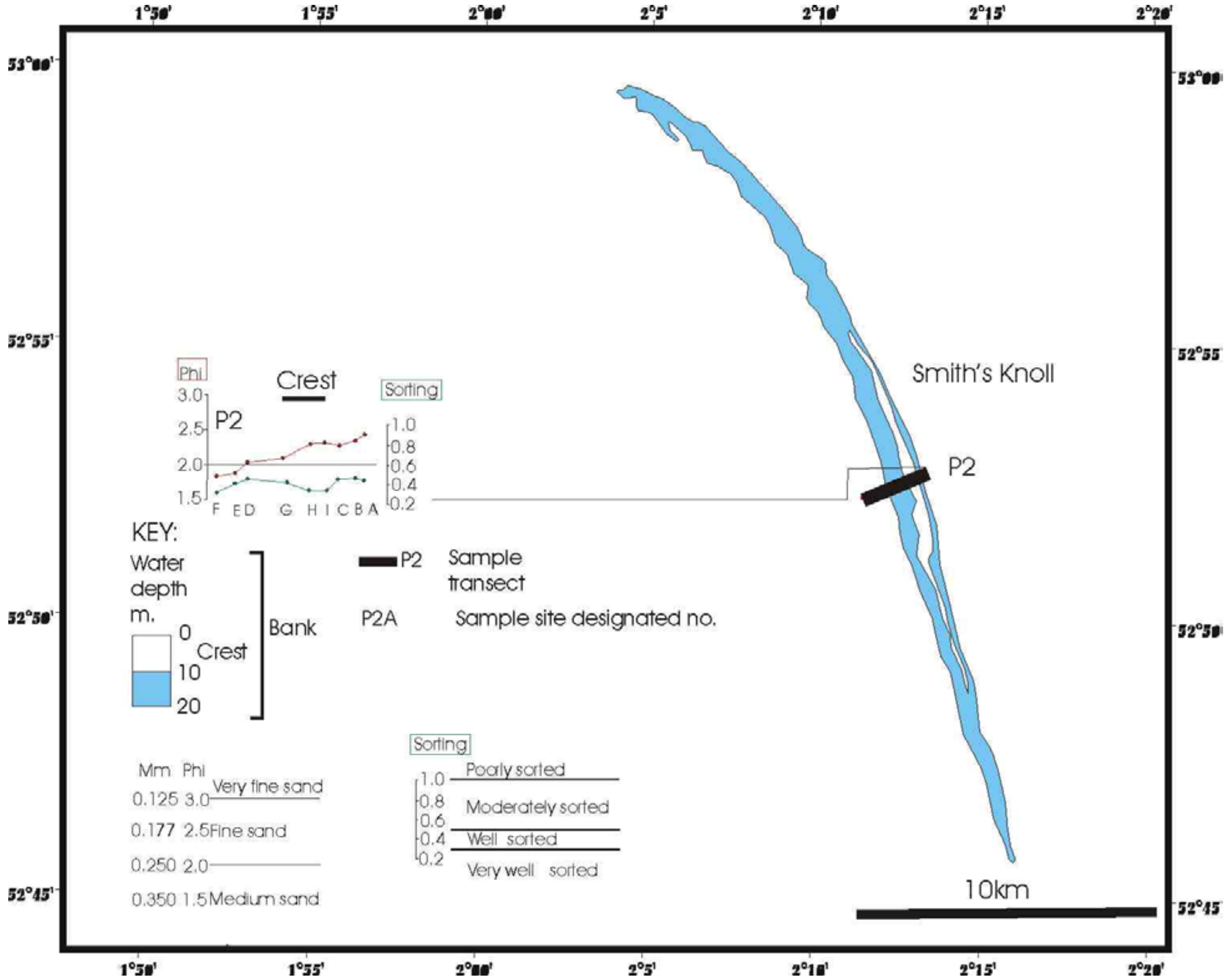


Figure 21 Smiths Knoll: mean grain size transect P 2

In Adobe Acrobat point for links with database of seabed photographs and sediment grain size analyses:

P2A P2B P2C P2D P2E P2F P2G P2H

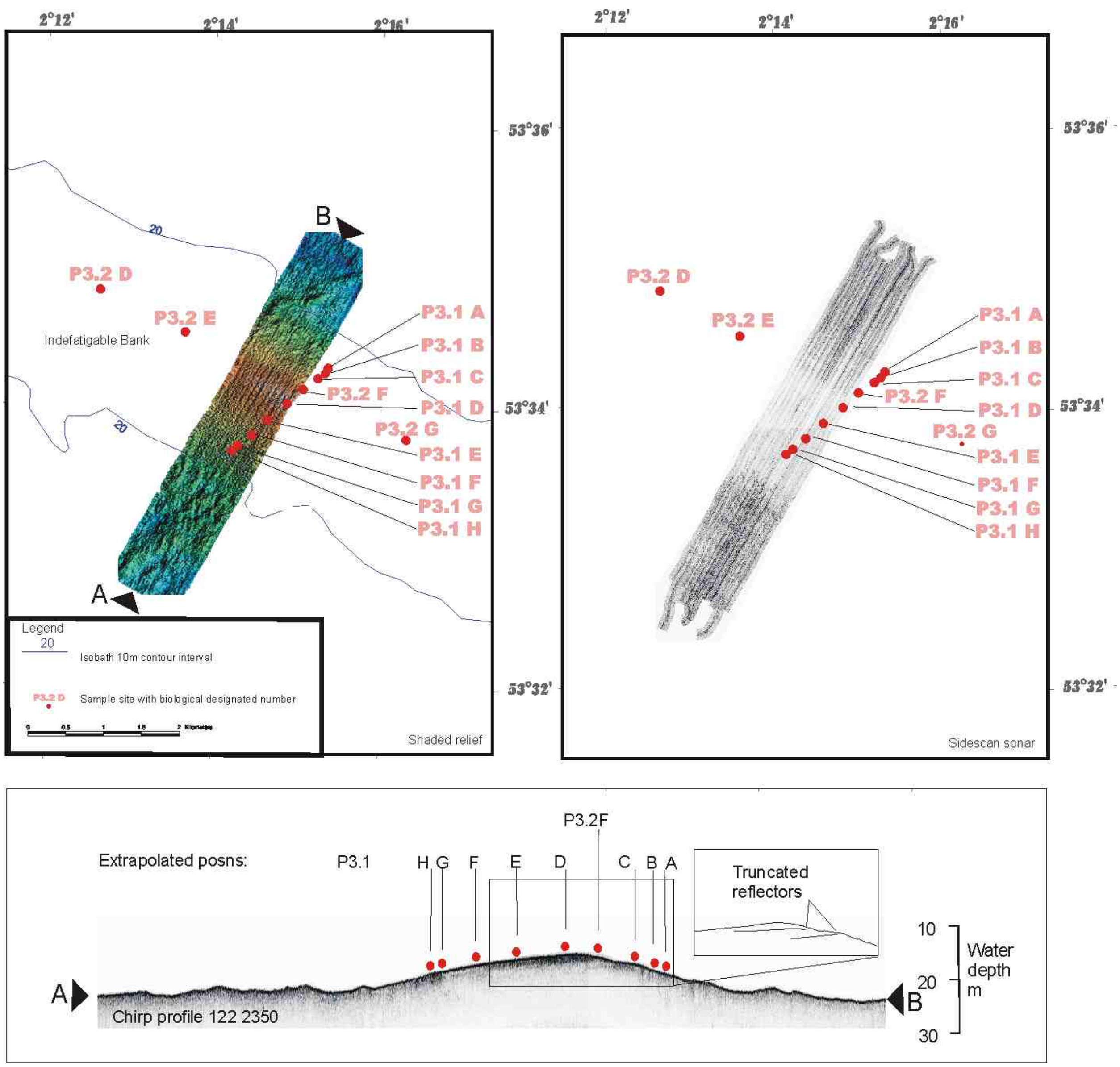


Figure 22 Indefatigable Bank North: seabed geomorphological setting and seismic reflection facies

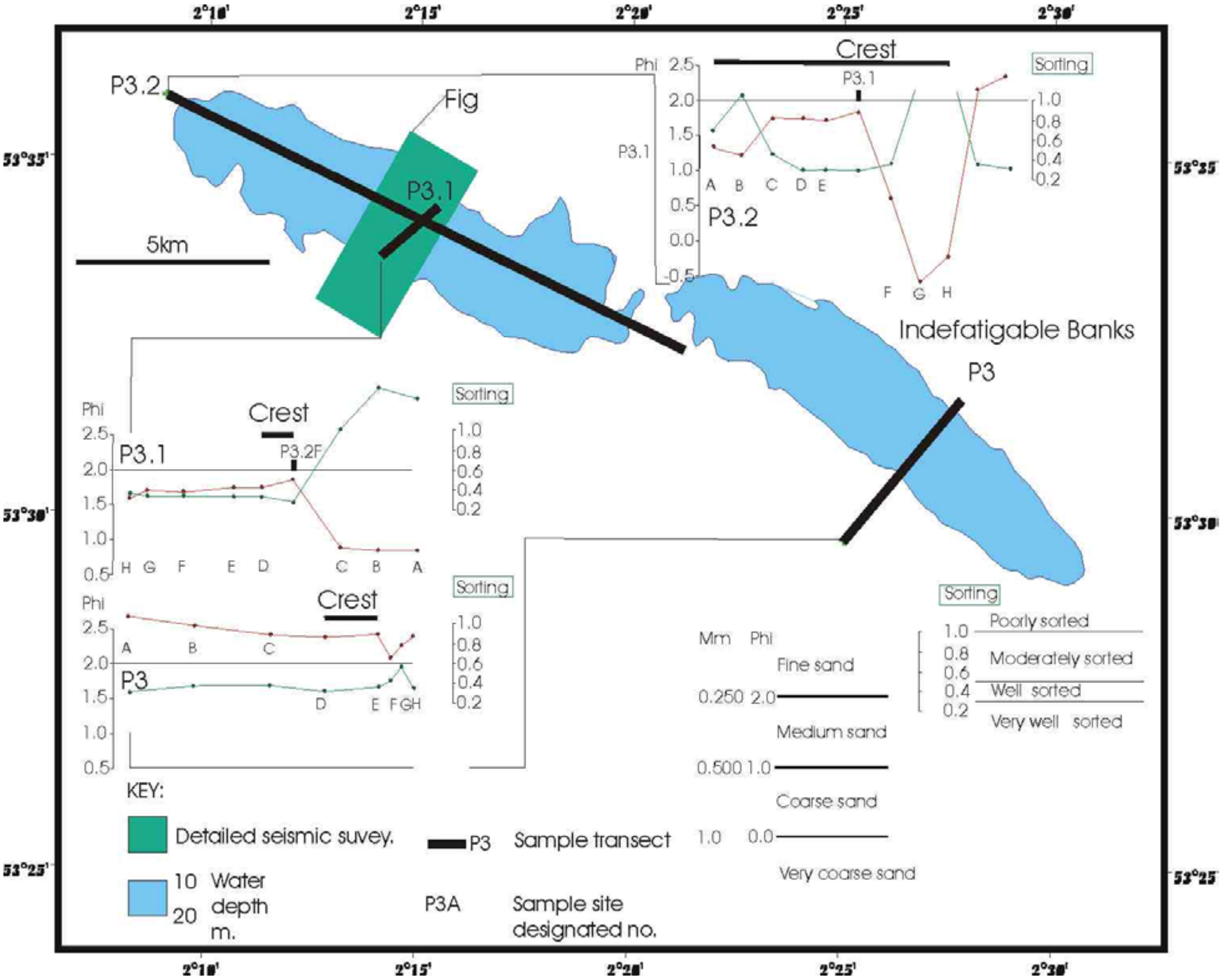


Figure 23 Indefatigable Banks: mean grain size transects P3, P3.1, P3.2

In Adobe Acrobat point for links with database of seabed photographs and sediment grain size analyses:

P3A P3B P3C P3D P3E P3F P3G P3H

P3.1A P3.1B P3.1C P3.1D P3.1E P3.1F P3.1G P3.1H

P3.2A P3.2B P3.2C P3.2D P3.2E P3.2F P3.2G P3.2H

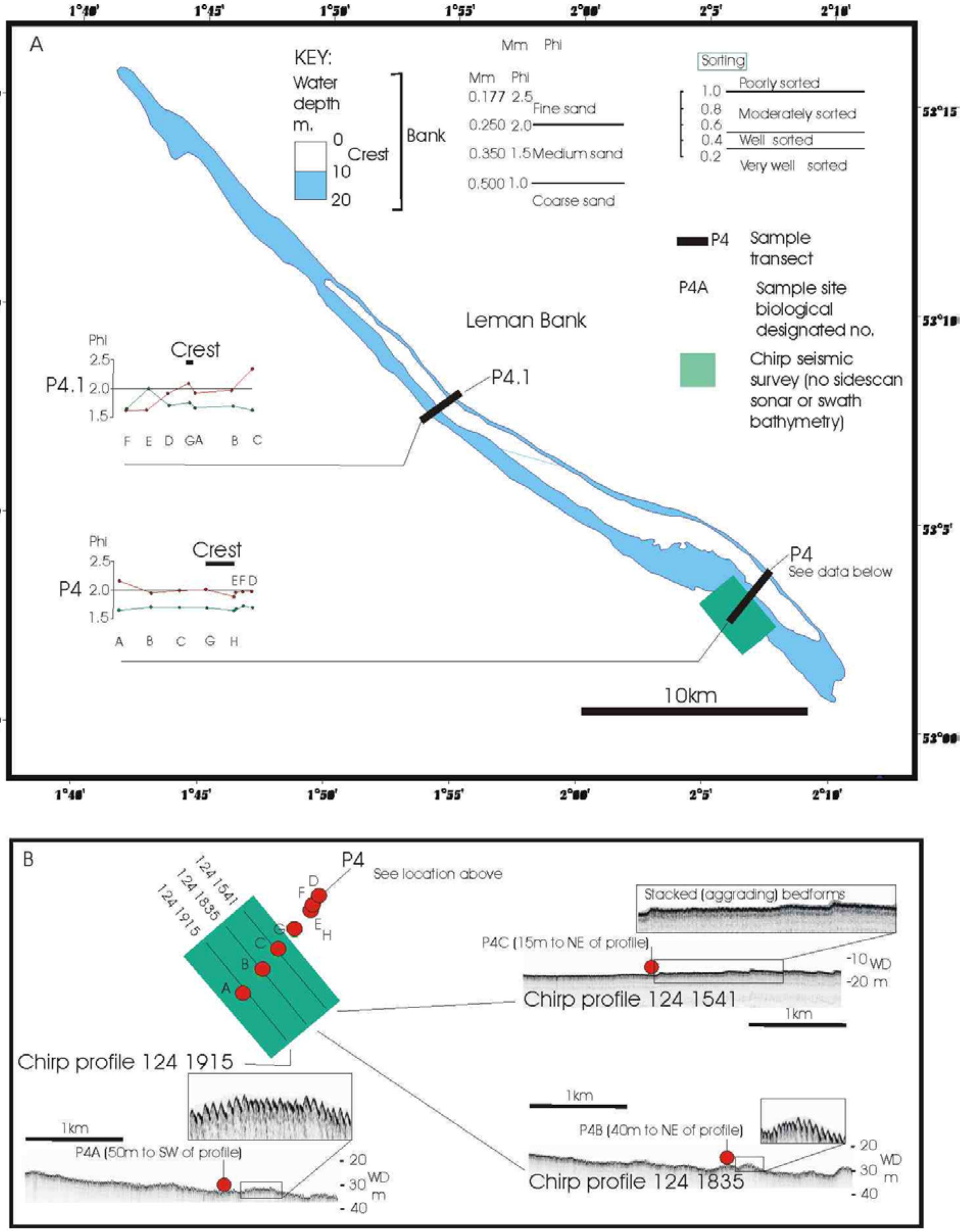


Figure 24 Leman Bank: mean grain size transects P4, P4.1 and seismic reflection facies

In Adobe Acrobat point for links with database of seabed photographs and sediment grain size analyses:

P4A P4B P4C P4D P4E P4F P4G P4H

P4.1 P4.1B P4.1C P4.1D P4.1E P4.1F P4.1G P4.1H

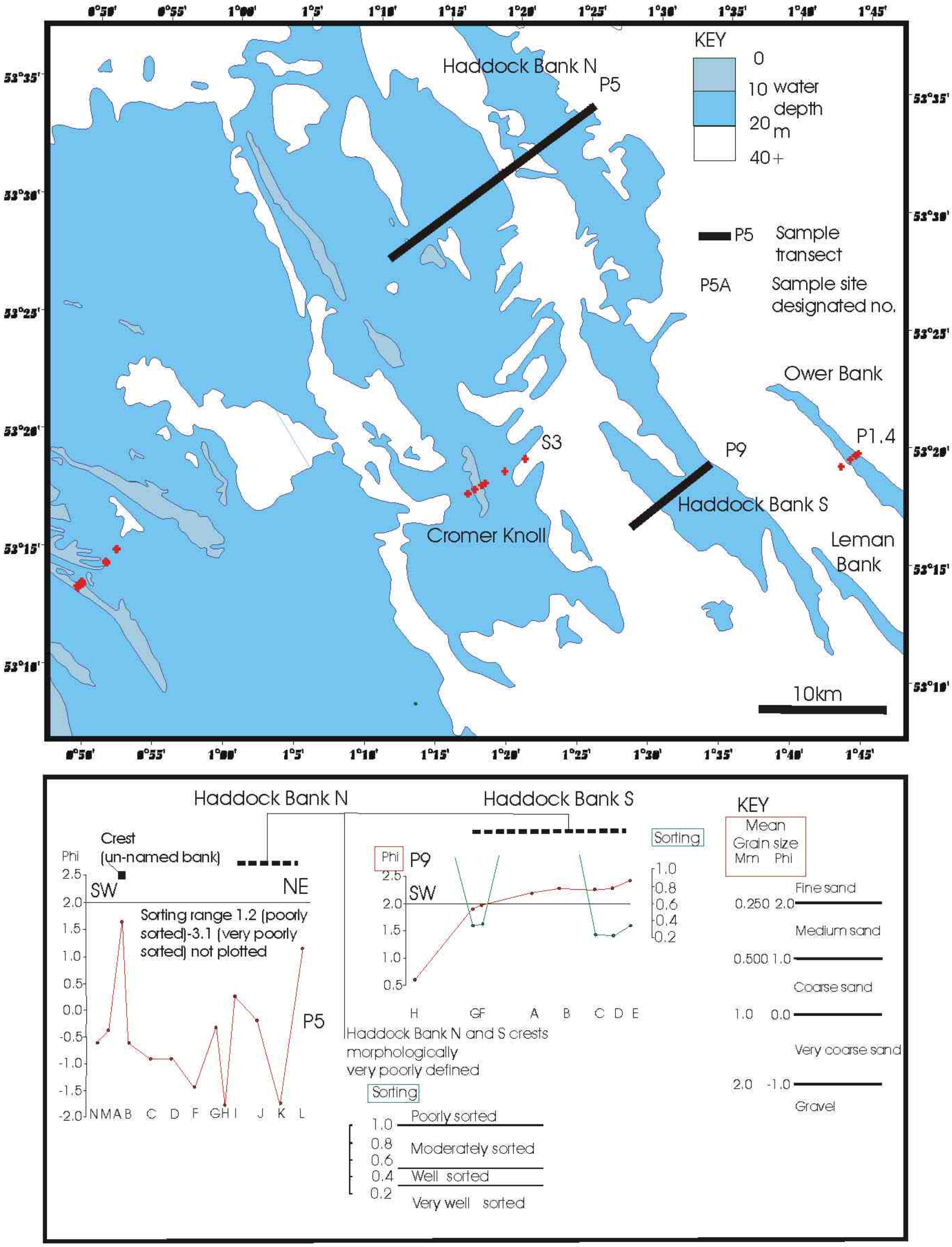


Figure 25 Haddock Bank North and South: mean grain size transects P5, P9

In Adobe Acrobat point for links with database of seabed photographs and sediment grain size analyses:

P5A P5B P5C P5D P5E P5F P5G P5H P5I P5J P5K P5L P5M P5N

P9A P9B P9C P9D P9E P9F P9G P9H

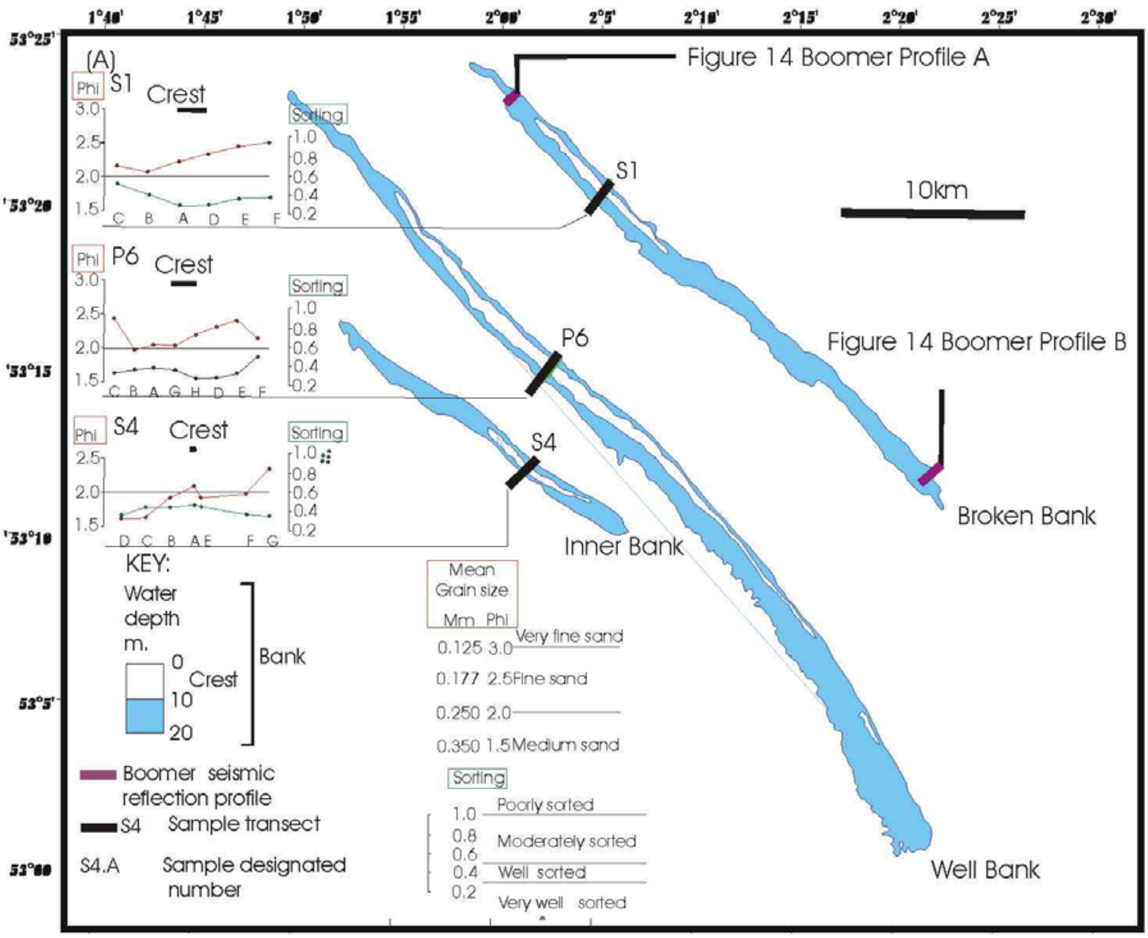


Figure 26 Inner Bank, Well Bank and Broken Bank: mean grain size transects P6, S1and S4 and sparker profile through northern Well Bank

In Adobe Acrobat point for links with database of seabed photographs and sediment grain size analyses:

P6A P6B P6C P6D P6E P6F P6G P6H

S1A S1B S1C S1D S1E S1F

S4A S4B S4C S4D S4E S4F S4G

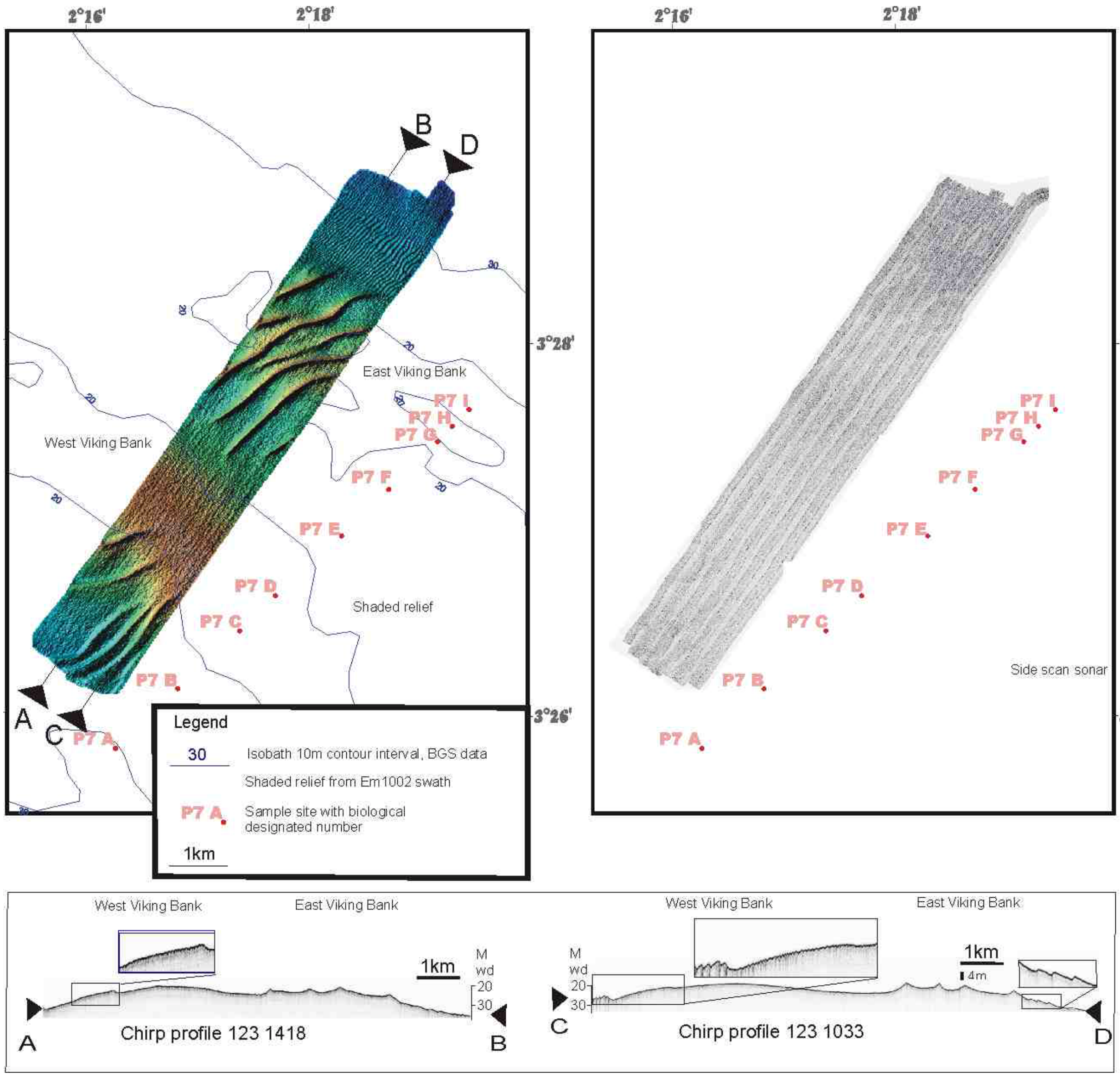


Figure 27 Viking Bank: seabed geomorphological setting and seismic reflection facies

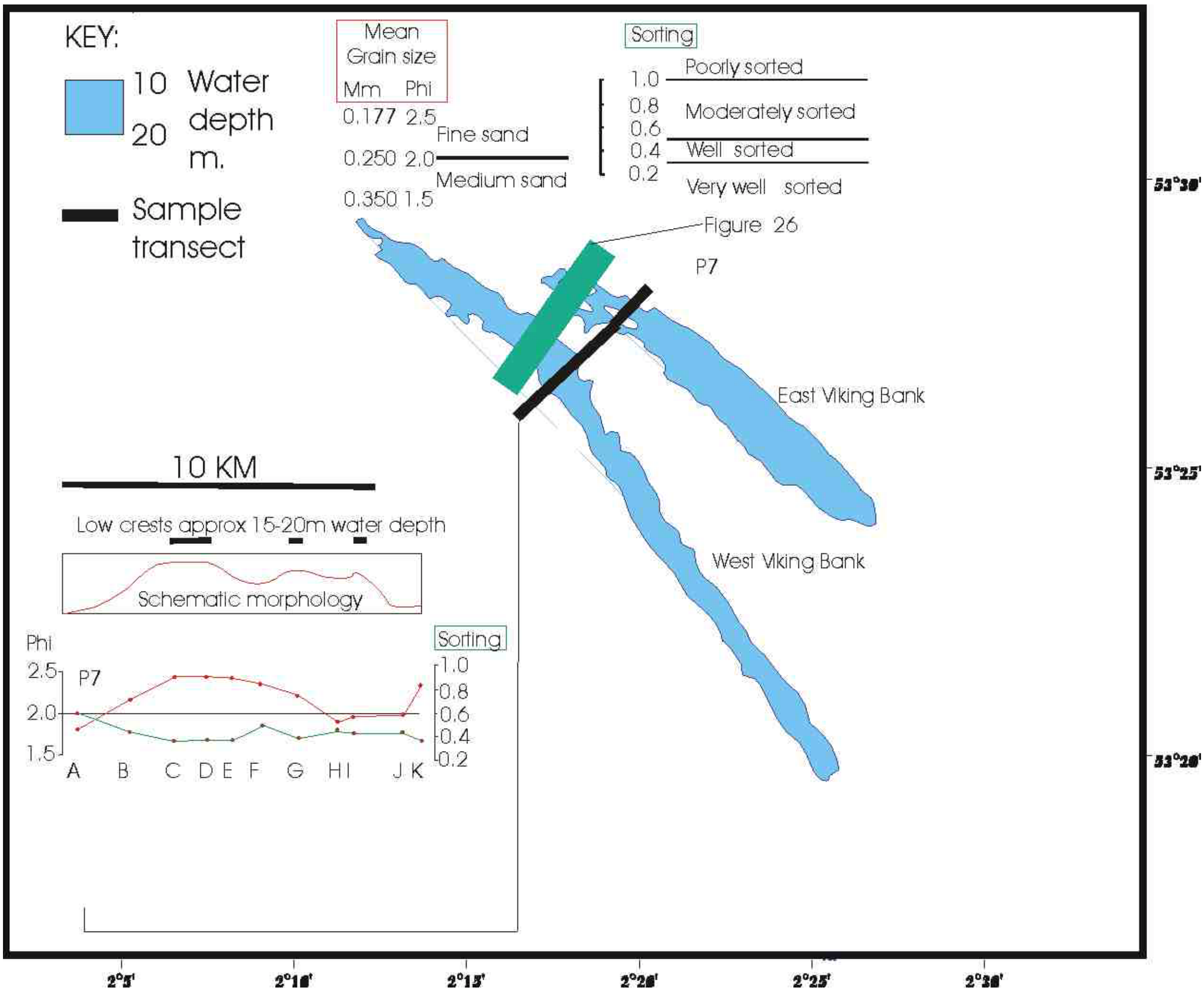
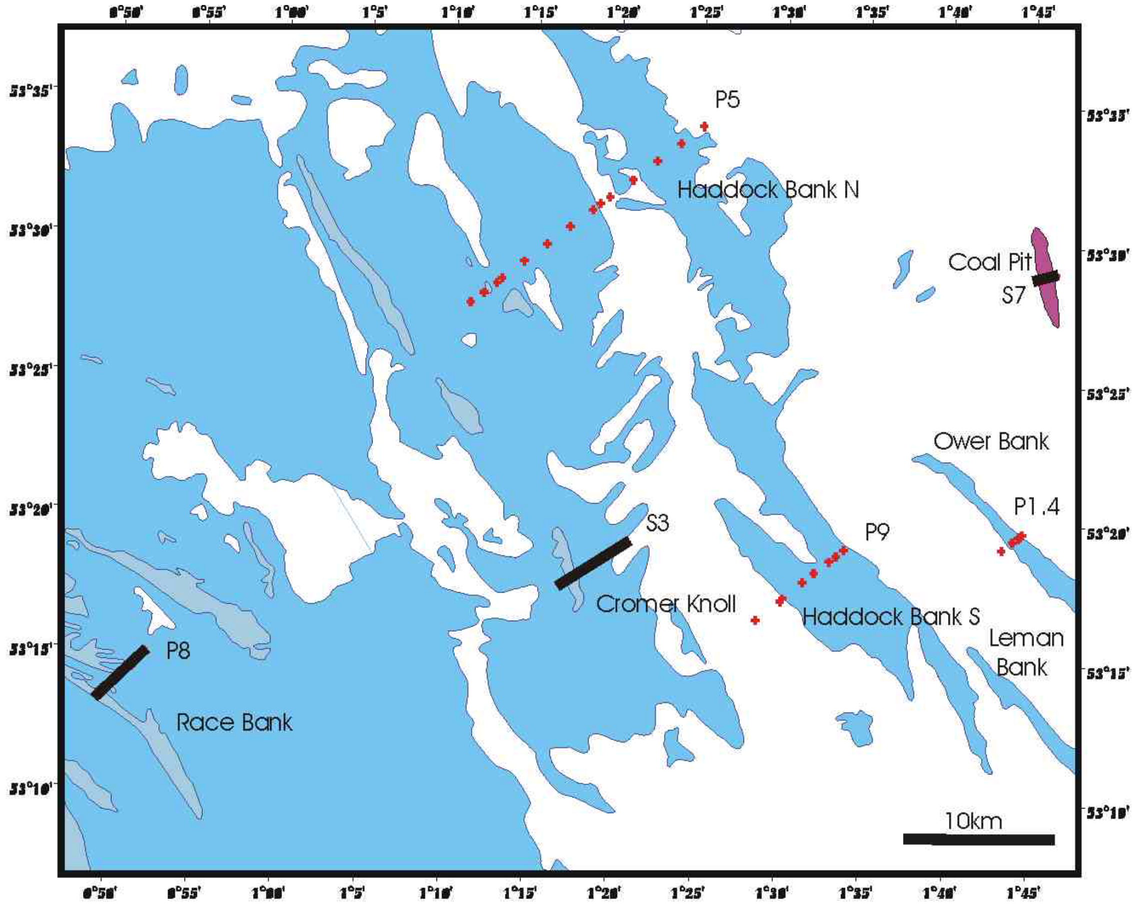


Figure 28 Viking Banks: mean grain size transect P7

In Adobe Acrobat point for links with database of seabed photographs and sediment grain size analyses:

P7A P7B P7C P7D P7E P7F P7G P7H



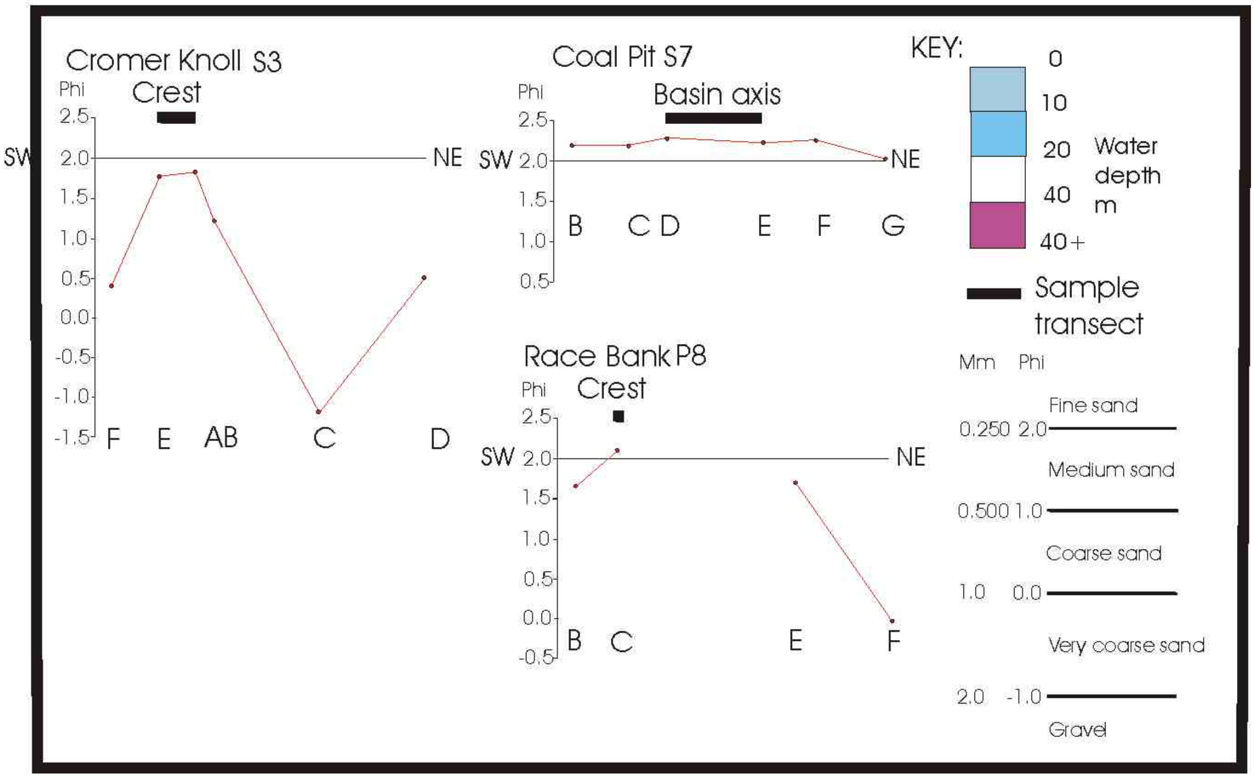


Figure 29 Race Bank, Cromer Knoll and Coal Pit: mean grain size transects P8, S3 and S7

In Adobe Acrobat point for links with database of seabed photographs and sediment grain size analyses:

P8B P8C P8E P8F S3A S3B S3C S3D S3E S3F S7**B** S7C S7D S7E S7F S7G

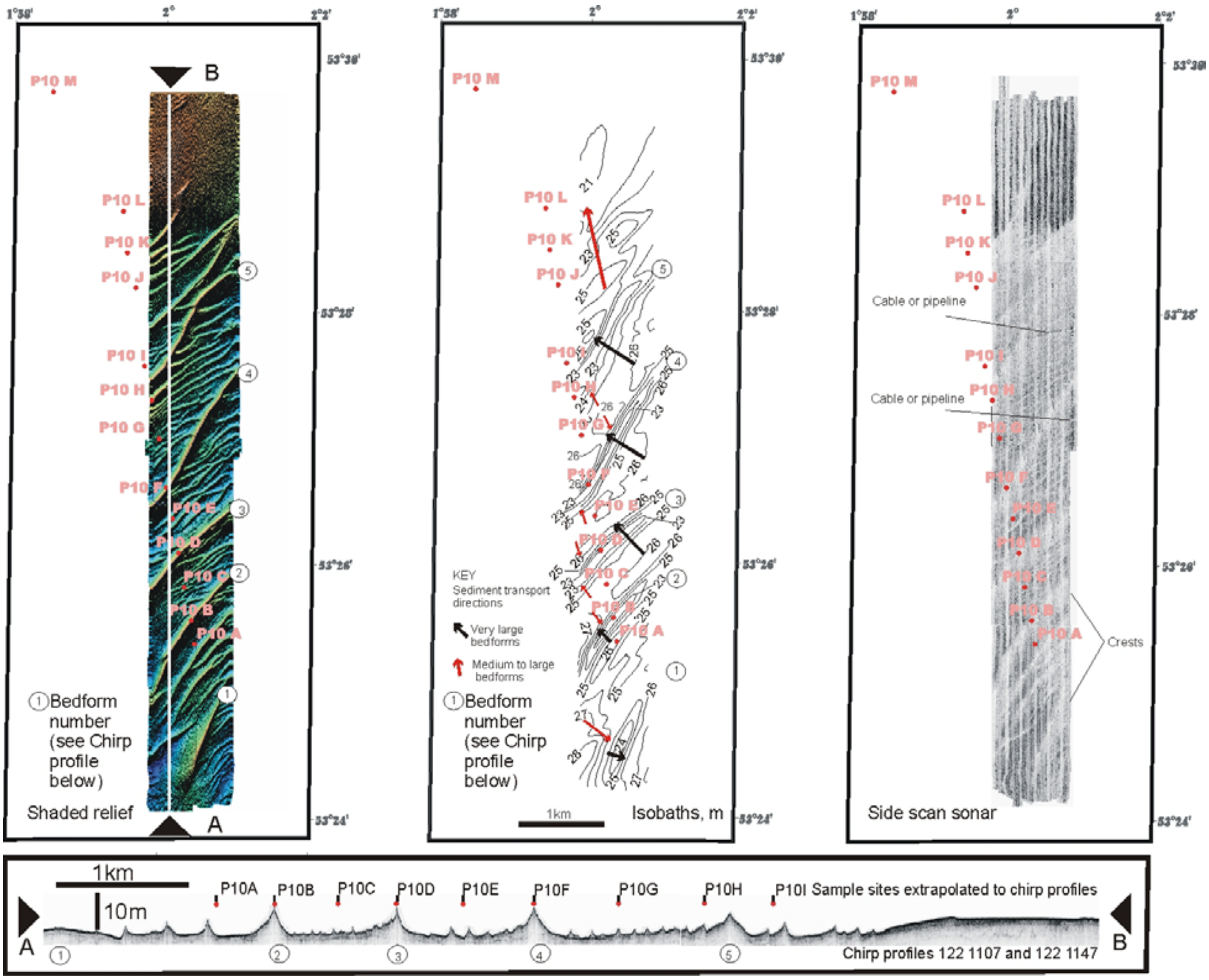


Figure 30 South-west of northern Swarte Bank: seabed geomorphological setting and seismic reflection facies

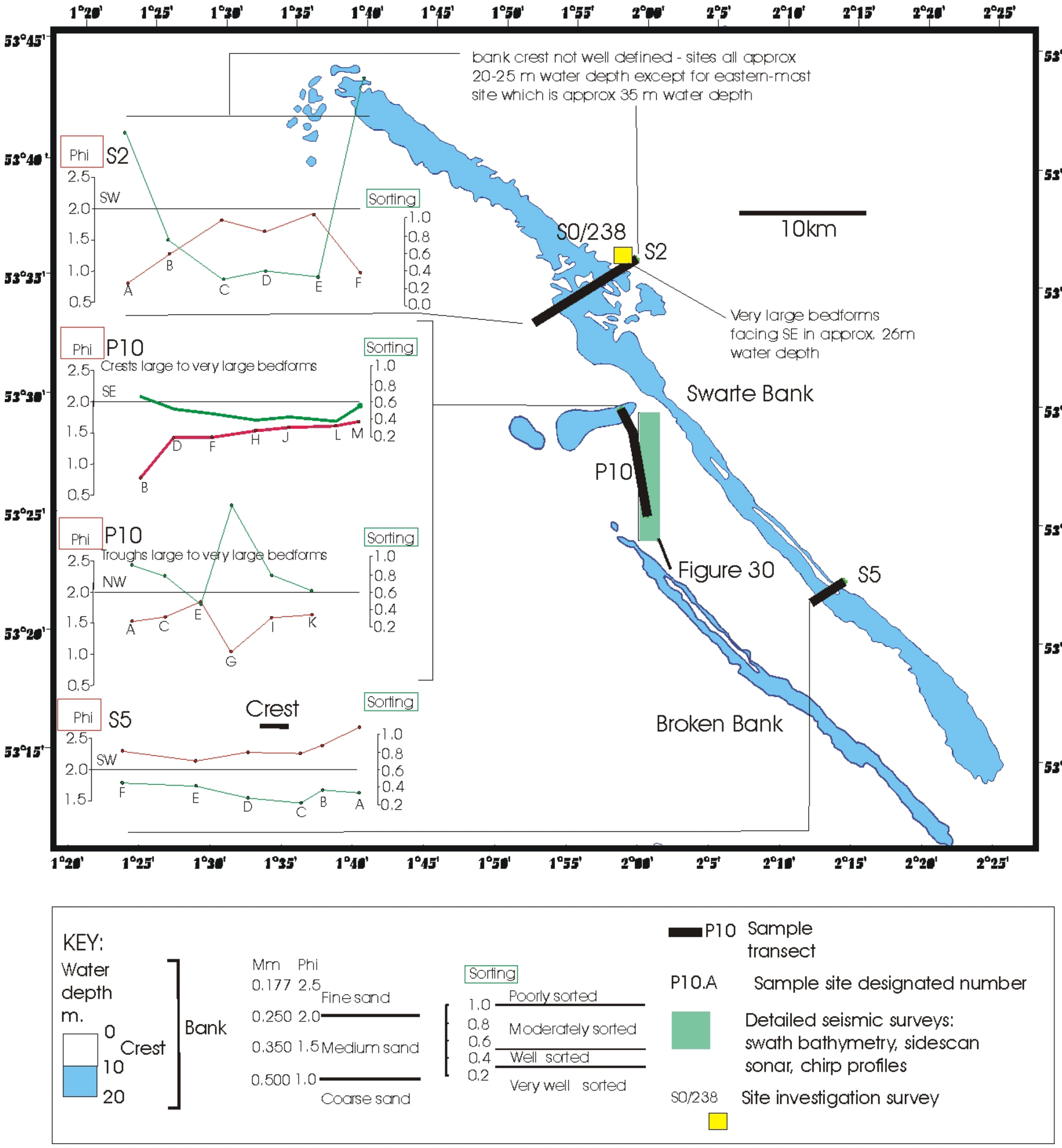


Figure 31 Swarte Bank and area to the south-west of Swarte Bank: mean grain size transects P10, S2, S5

In Adobe Acrobat point for links with database of seabed photographs and sediment grain size analyses:

P10A P10B P10C P10D P10E P10F P10G P10H P10I P10J P10K P10L P10M

S2A S2B S2C S2D S2E S2F

S5A S5B S5C S5D S5E S5F

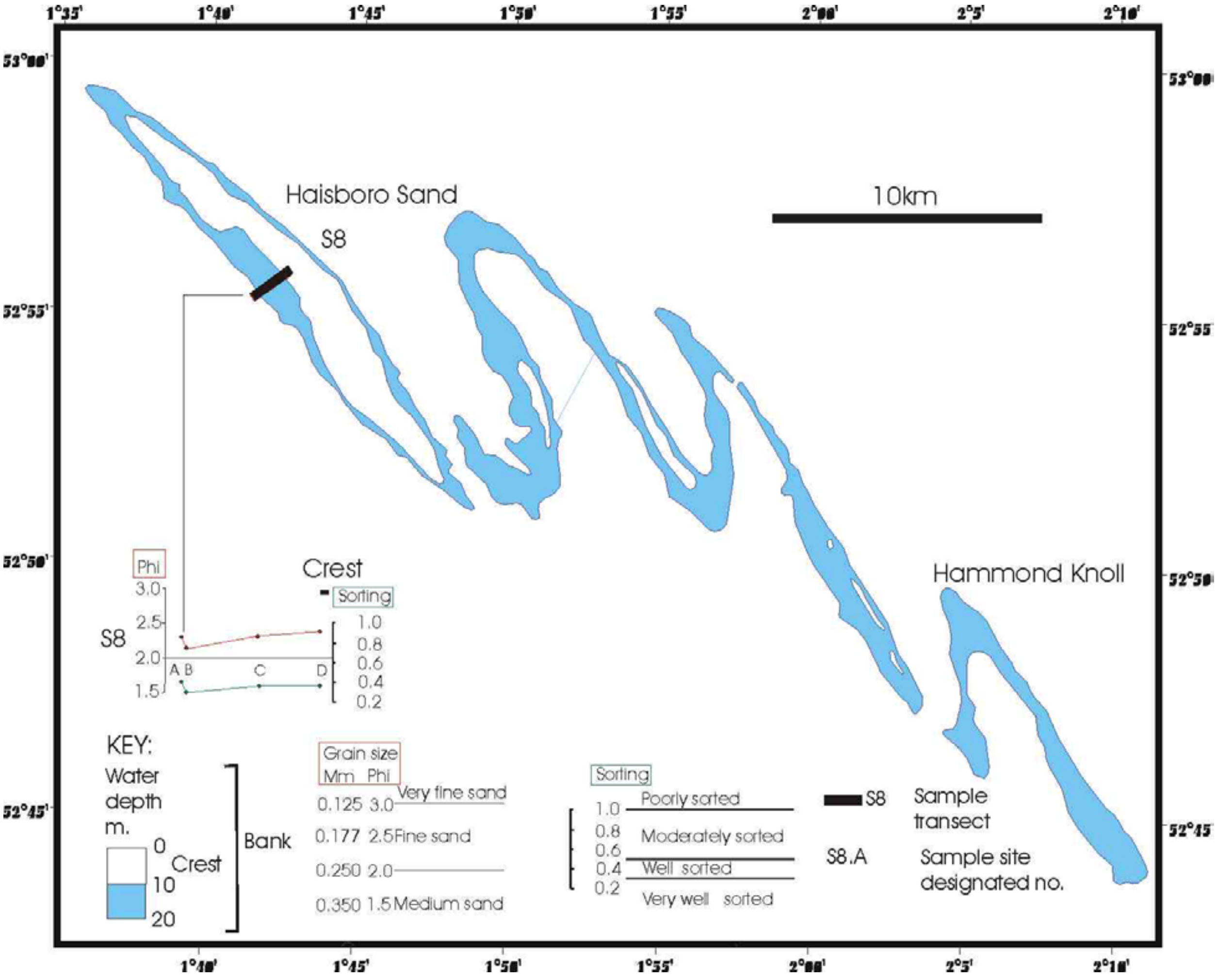


Figure 32 Haisboro Sand: mean grain, grain size transect S8

In Adobe Acrobat point for links with database of seabed photographs and sediment grain size analyses:

S8A S8B S8C S8D

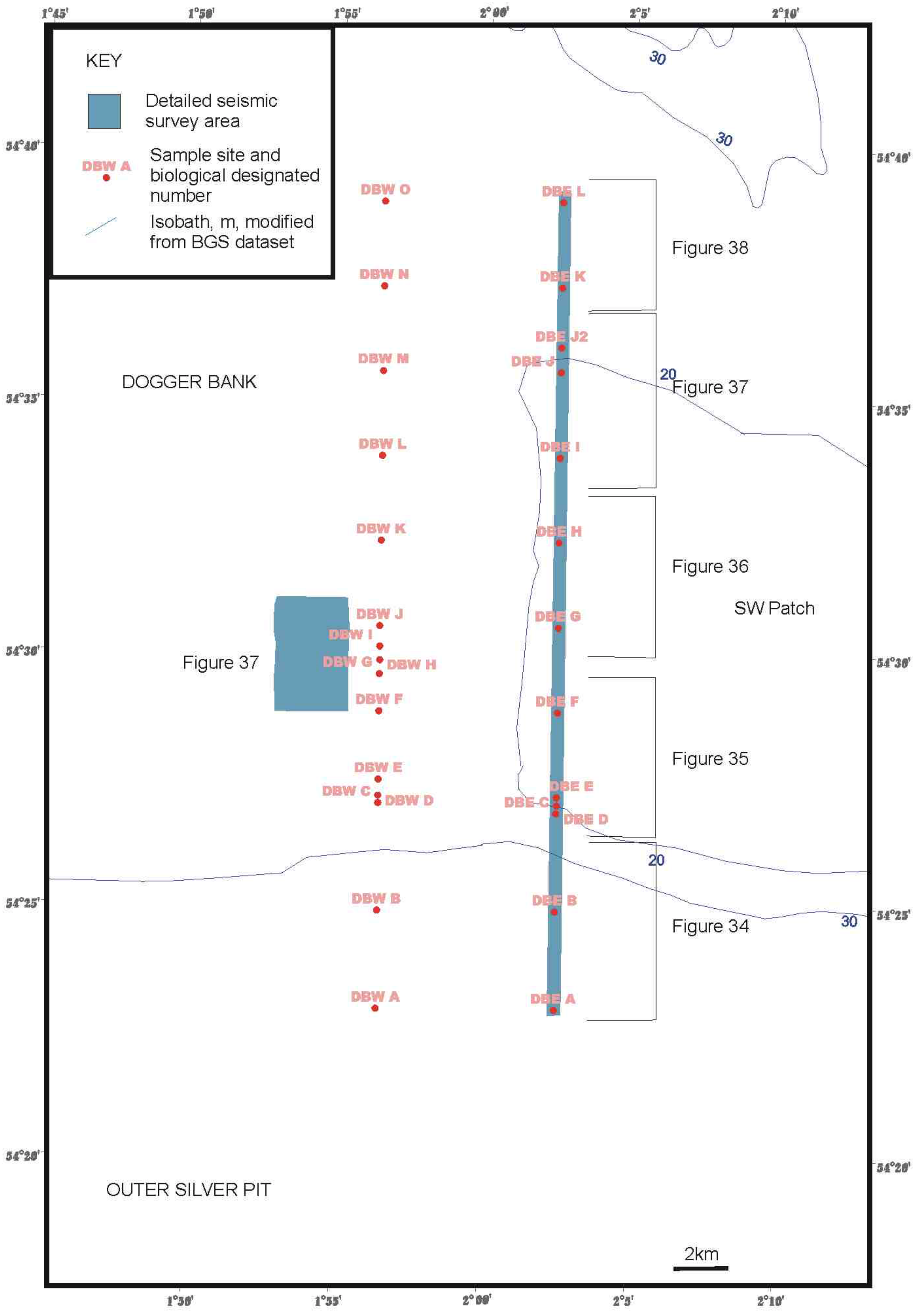


Figure 33 Dogger Bank: locations of panels describing survey areas

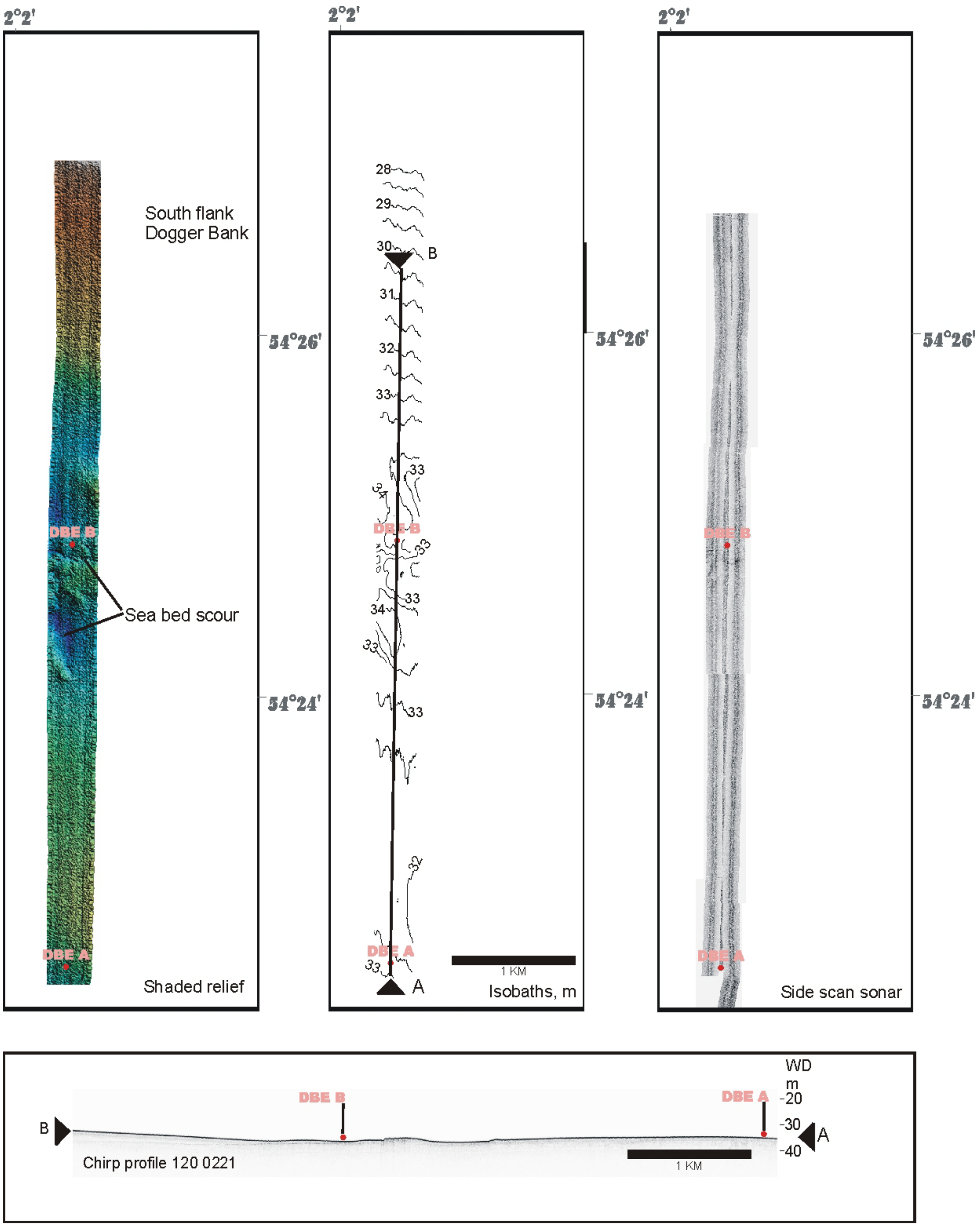


Figure 34 Dogger Bank East: seabed morphological setting and seismic reflection facies, panel 1 of 5

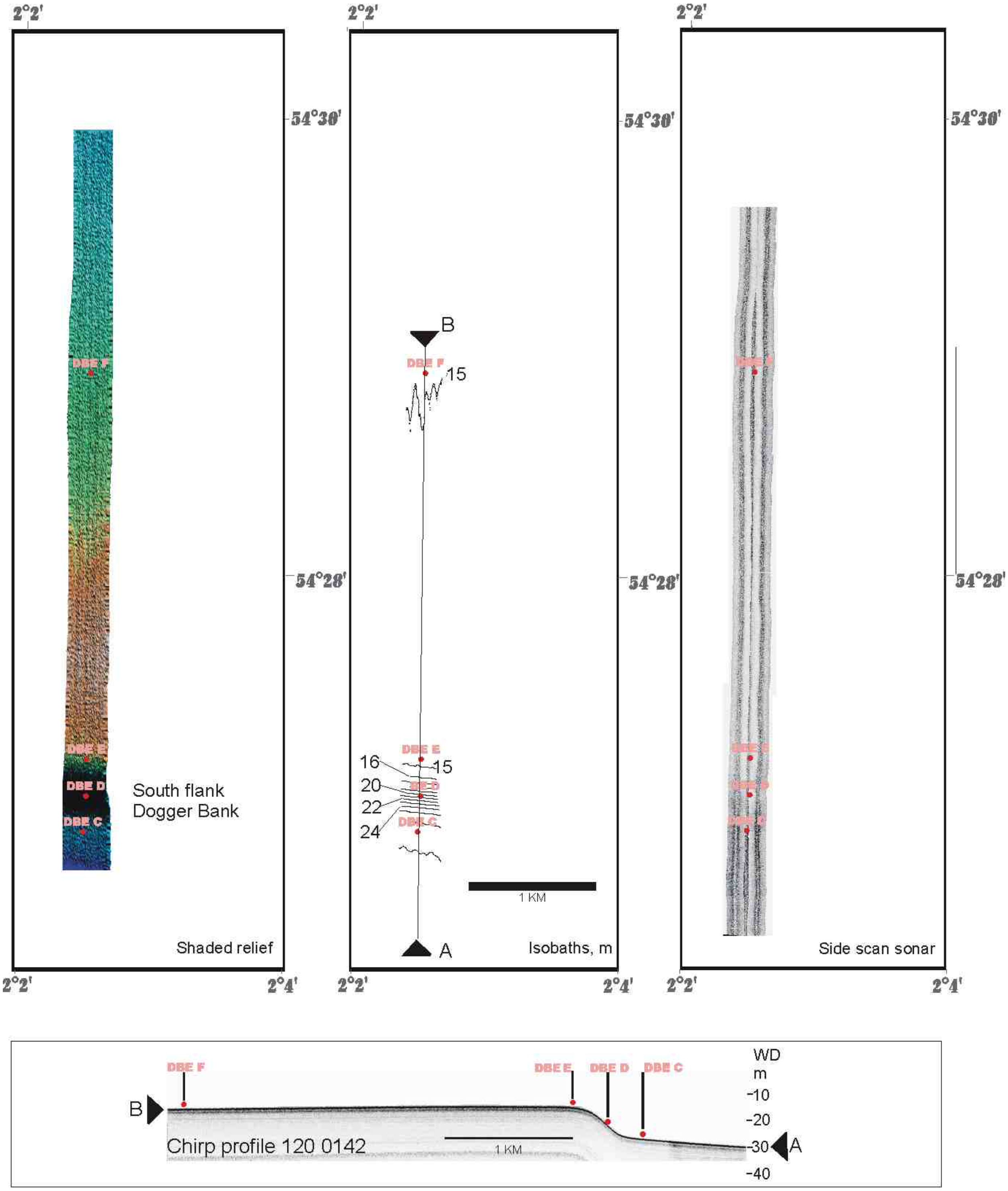


Figure 35 Dogger Bank East: seabed geomorphological setting and seismic reflection facies, panel 2 of 5

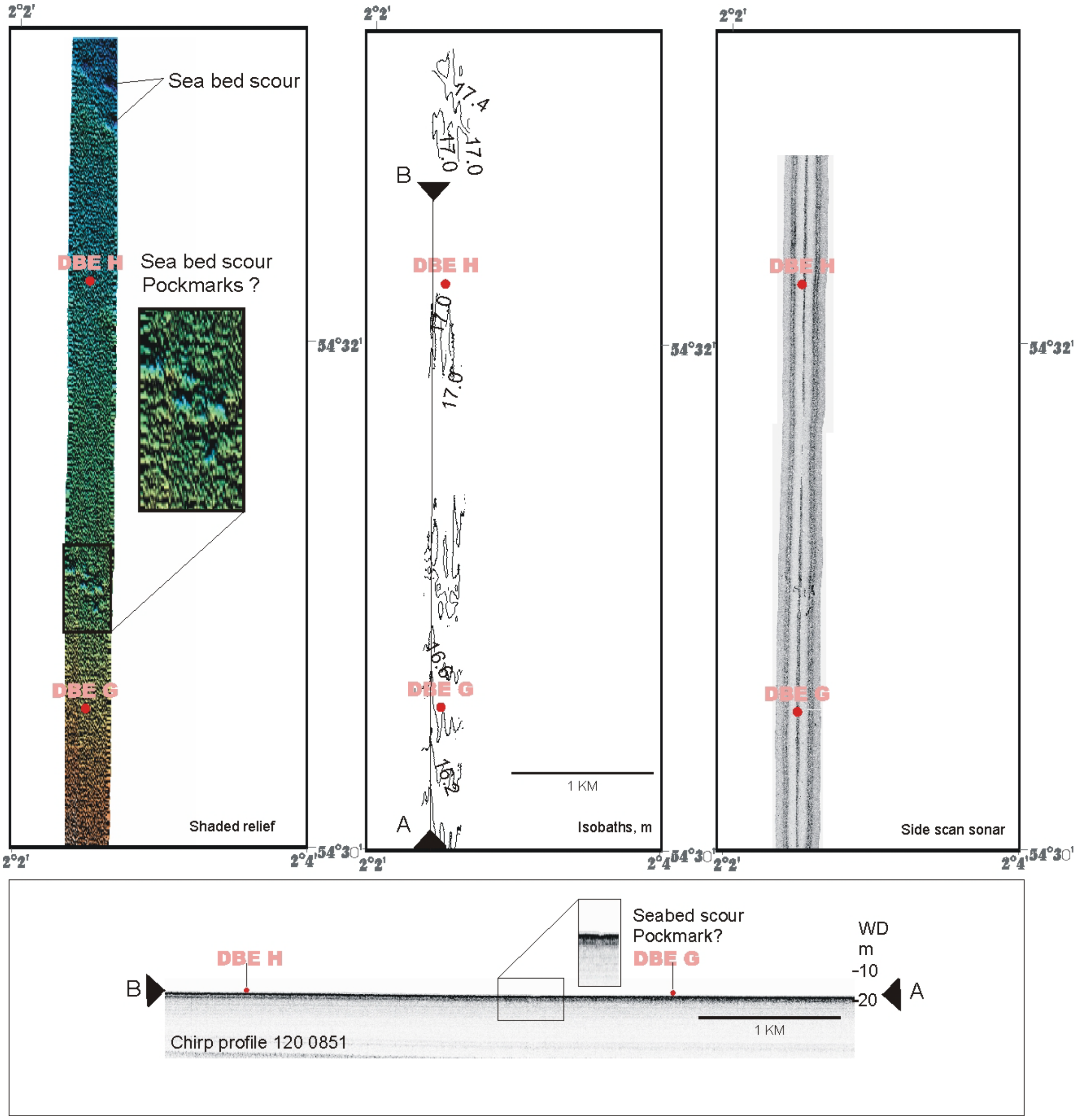


Figure 36 Dogger Bank East: seabed geomorphological setting and seismic reflection facies, panel 3 of 5

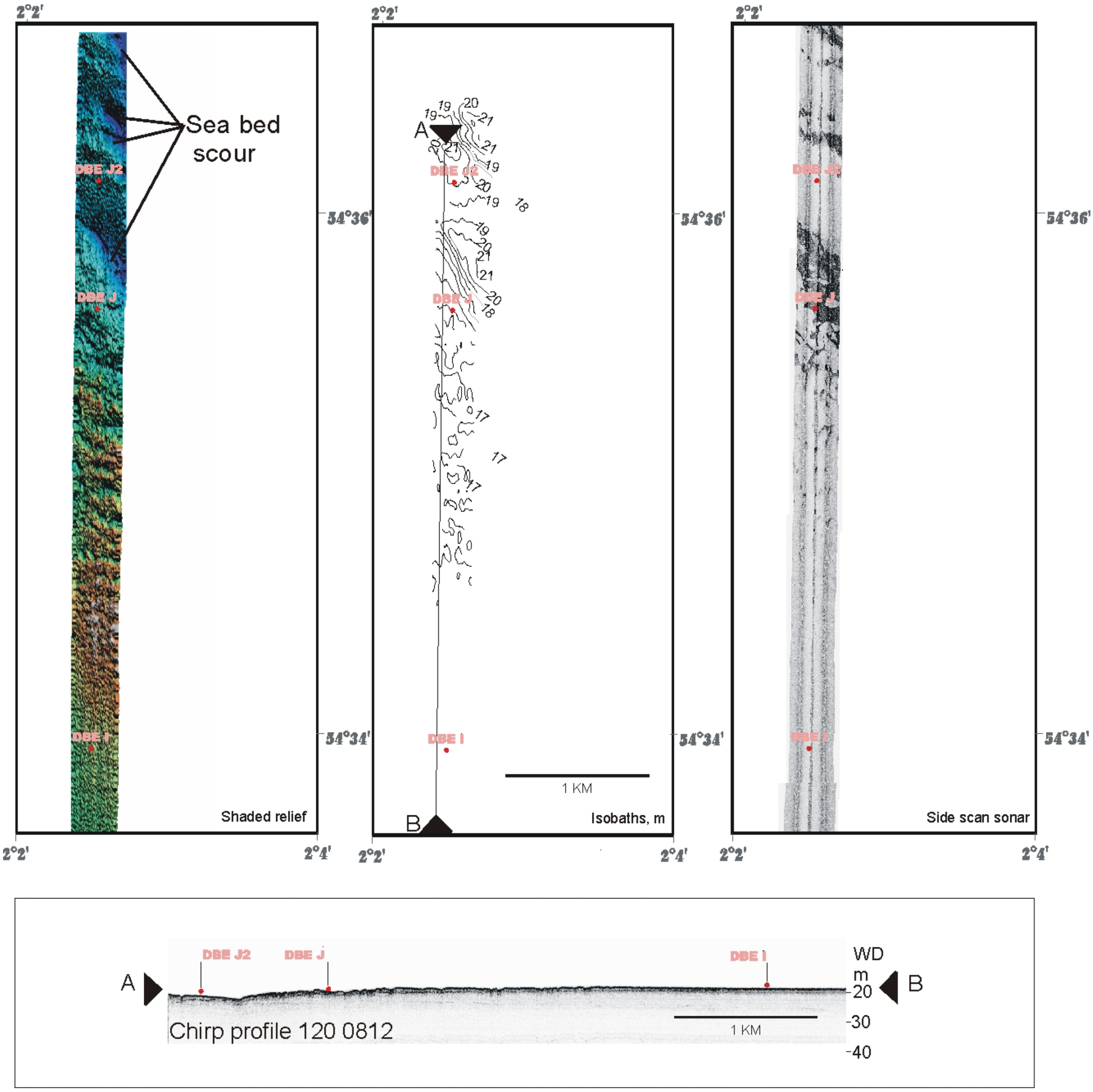


Figure 37 Dogger Bank East: seabed geomorphological setting and seismic reflection facies, panel 4 of 5

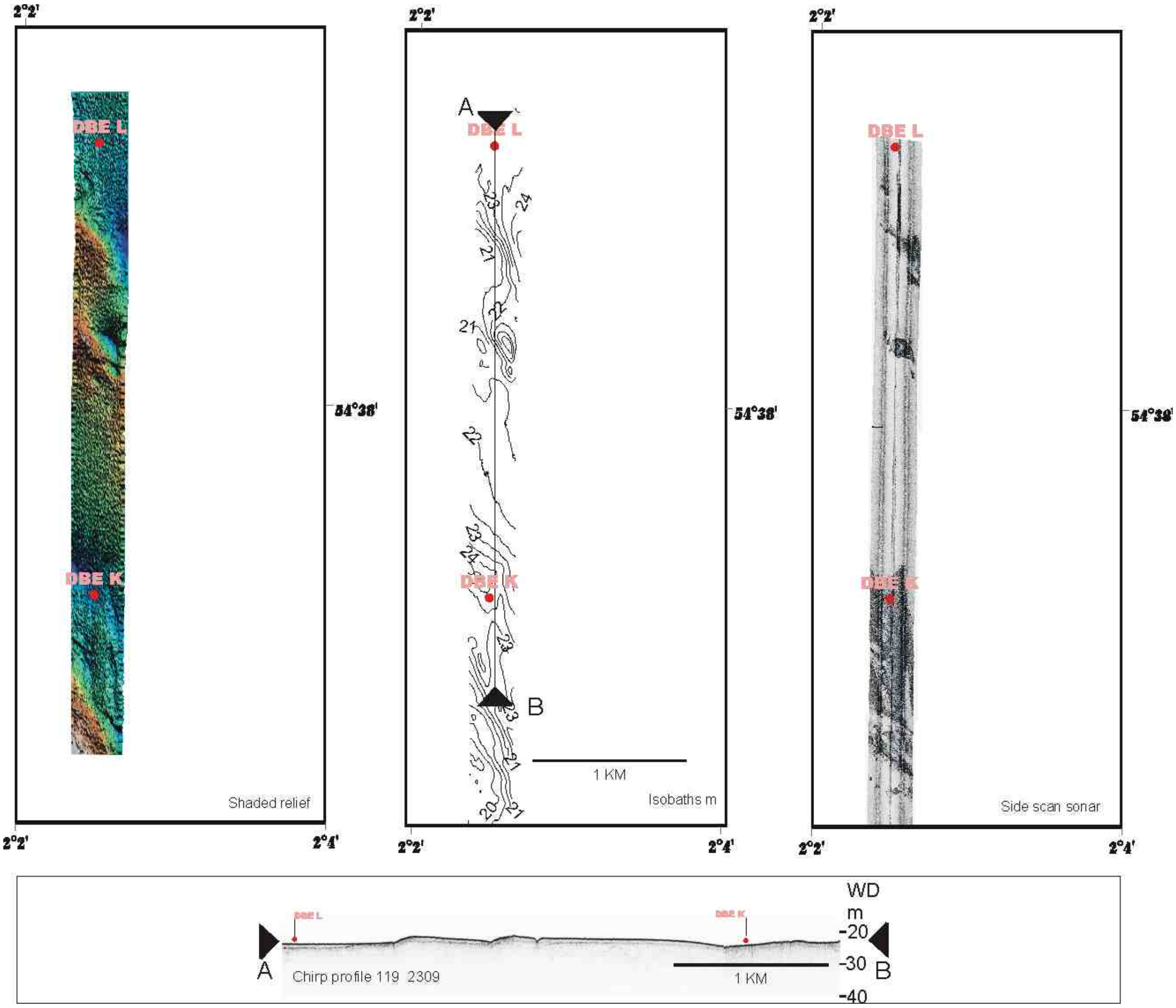


Figure 38 Dogger Bank East: seabed geomorphological morphological setting and seismic reflection facies, panel 5 of 5

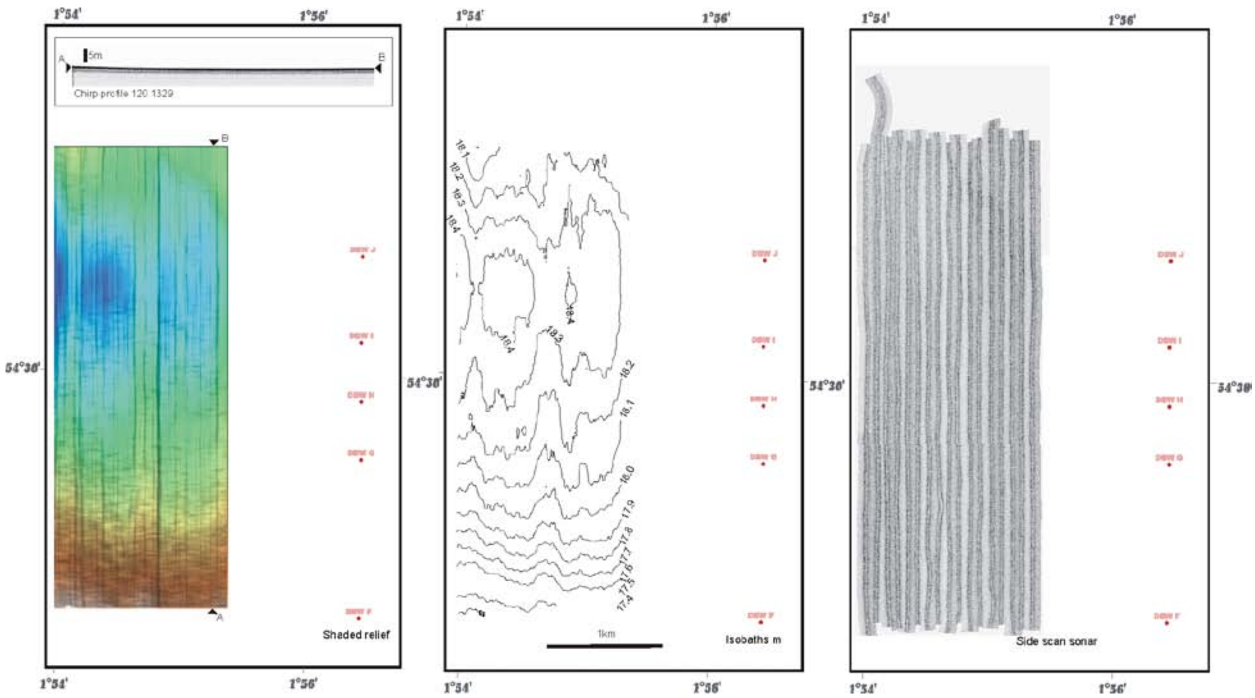


Figure 39 Dogger Bank West: seabed geomorphological setting and seismic reflection facies

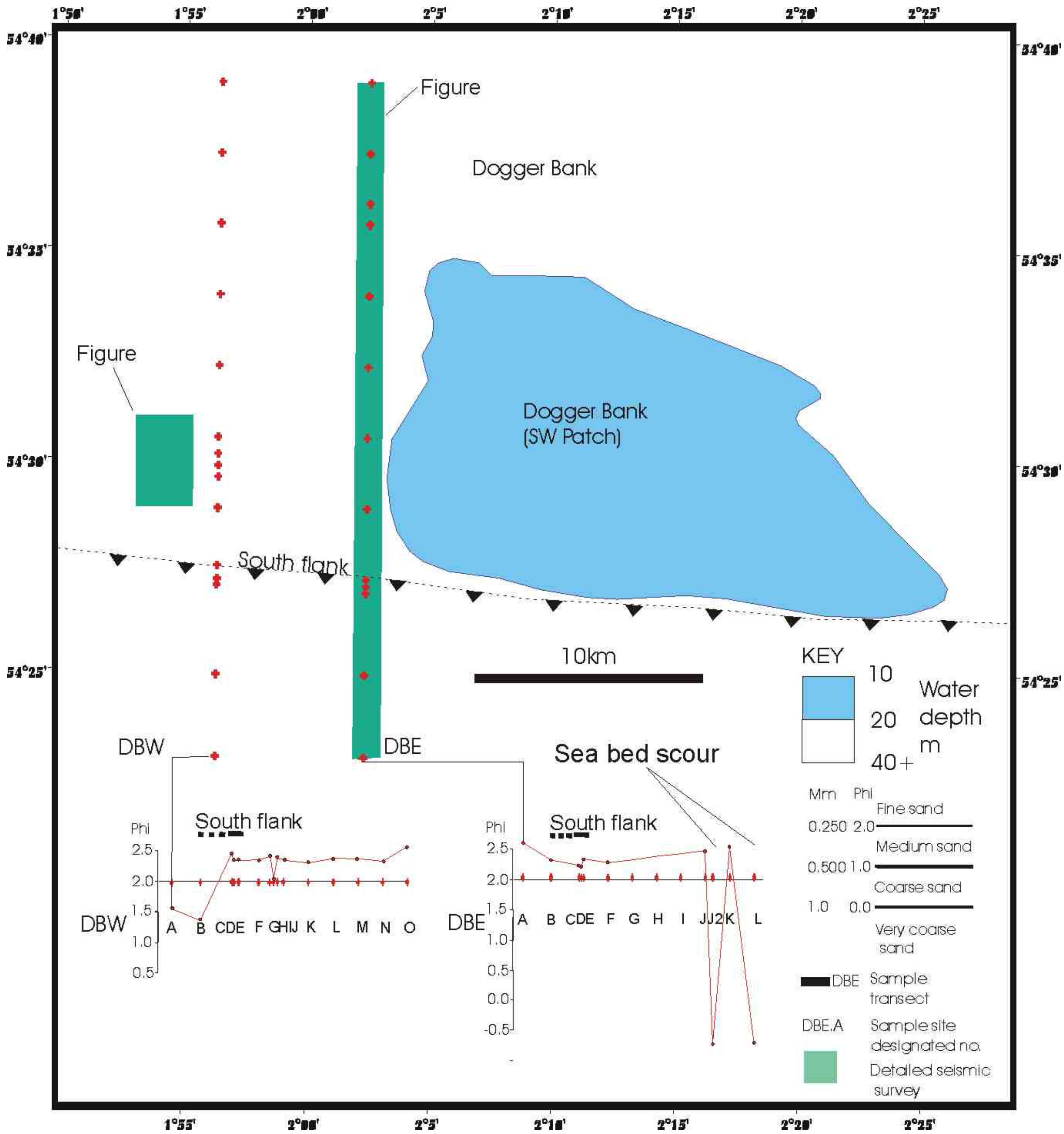


Figure 40 Dogger Bank East and West: mean grain size transects DBE and DBW

In Adobe Acrobat point for links with database of seabed photographs and sediment grain size analyses:

DBEA DBEB DBEC DBED DBEF DBEG DBEH DBEI DBEJ DBEJ2 DBEK DBEL

DBWA DBWB DBWC DBWD DBWE DBWF DBWG DBWH DBWI DBWJ DBWK DBWL DBWM DBWN DBWO

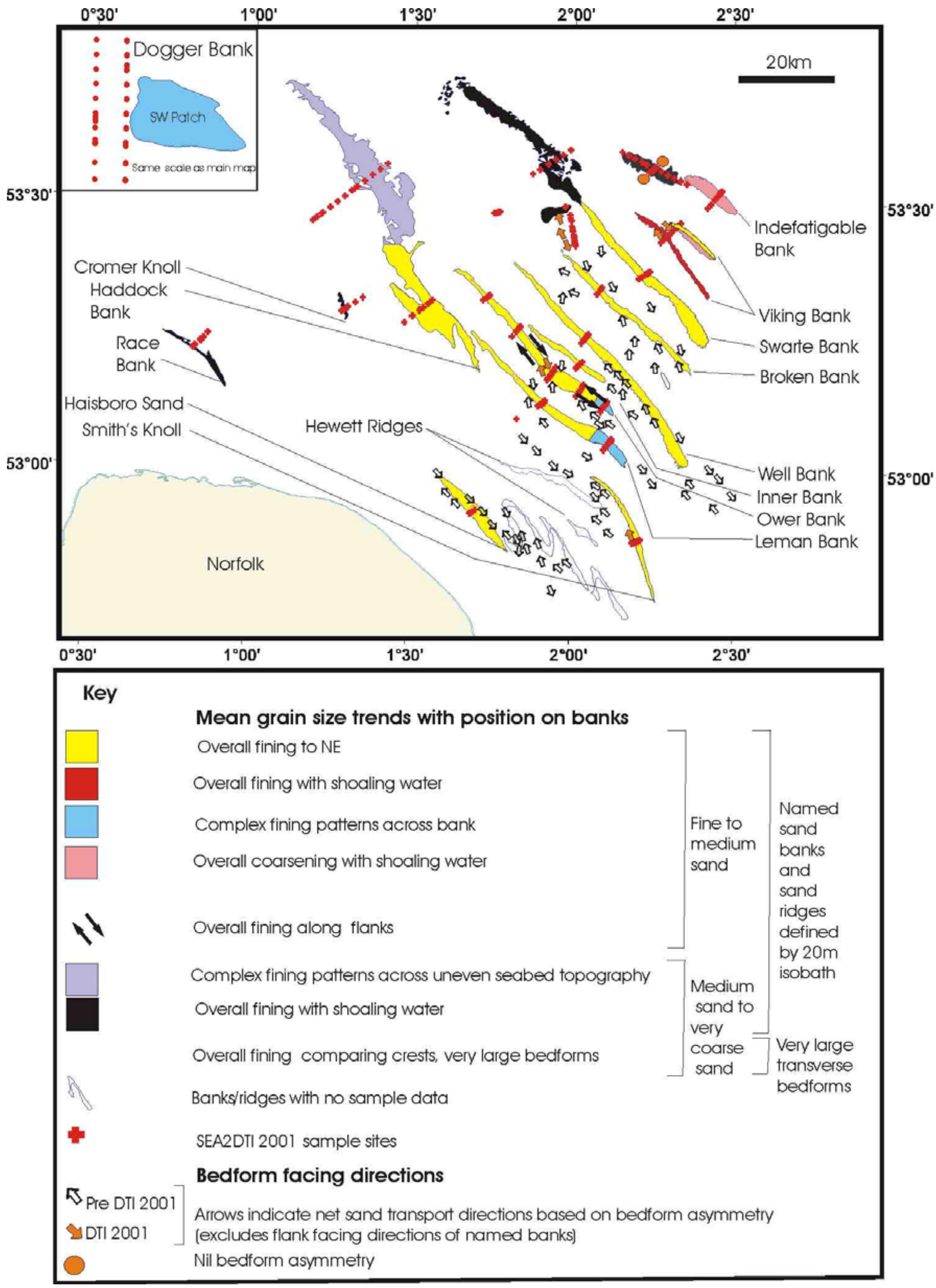


Figure 41 Norfolk Banks and Dogger Bank: regional sediment transport pathways derived from mean grain size variations and bedform facing directions

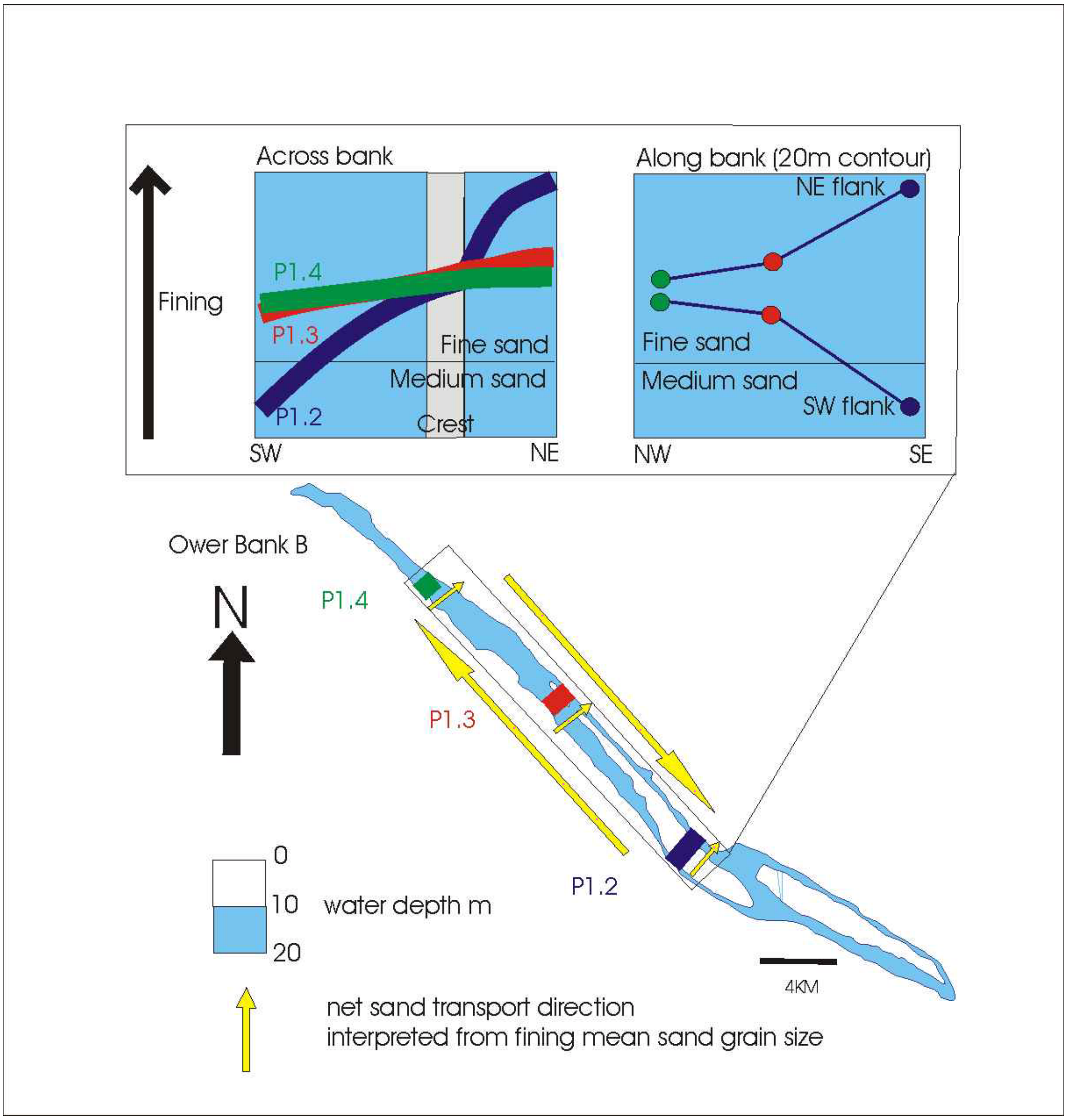


Figure 42. Sediment transport directions derived from variations in mean grain size around Ower Bank B

Appendix 1 Classifications used in the European Submerged Sandbanks Database

Appendix 1Classifications used in the European Submerged Sandbanks Database

REMARK	EXPLANATION
ID NO	Banks are individually numbered from 1 (Straits of Dover) to 457 (Aegean Sea).
SITE NAME	The name of the banks is taken from charts. This particular field is left blank when the bank is unnamed.
SITE CLASSIFICATION	The banks have been categorised as linear, asymmetric linear, radial, asymmetric radial, irregular, bank cluster and 'diffuse (these descriptions are sketched below). The classification was based, in general terms, on the description of Dyer and Huntley (1999) and the plan shape of the bank.
GEOGRAPHICAL LOCATION	In order to make the location of each bank easier, the area was divided into 24 regions. The delimitation of these regions is based (generally) on established divisions (such as the English Channel or the Irish Sea) and not on legal maritime boundaries. These boundaries a re delimited by latitude and longitude boxes (see Appendix IV).
POSITION	Referred to the mid-pint of the bank and expressed as (decimal) Latitude and Longitude.
WATER DEPTH	The height of the water column (in meters) above the mid-point of the bank. All depths are reduced to Chart Datumn, which, in most cases, is the water depth associated with the Lowest Astronomical Tide (LAT). This location is not necessarily the highest point on the bank.
SITE DIMENSIONS	The approximate area of the banks, estimated from the Admiralty Charts. The length and width of each bank was measured directly from the charts. These dimensions were used then to calculate the plan surface area of the bank.

BANK HEIGHT	The height is defined as the elevation of the bank at the mid-point, relative to the surrounding (level) seabed.
SITE ORIENTATION	The orientation is expressed as N-S or E-W.
SEDIMENT COMPOSITION	The information was obtained from the Admiralty Charts. In the case where the sediment type was not indicated on the bank itself, the composition was assumed to be similar to that of the surrounding seabed.
GENERAL DESCRIPTION	This provides a summary of the main features of each bank including: basic plan shape; surface topography; the gradient of the sides and any other interesting features. Additionally, the topography and sediment composition of the surrounding seabed is highlighted.
CHART DETAILS	Chart No, Title, Scale and Date of Chart.
STATE JURISDICTION	The State within whose waters a particular bank is located. For banks lying in international waters or disputed waters (e.g. in straits), the state jurisdiction simply refers to the legislative country.

Classification of submarine sandbanks based on plan shape

Linear	
Asymmetric linear	
Radial	
Asymmetric radial	
Irregular	
Clusters of banks	Two or more banks that are closely grouped. The individual banks may fall into any of the above categories.
Diffuse	Any bank that is named on a chart but where the boundaries are not defined clearly in the representation

Appendix 2. Commercial site investigation reports reviewed

In the following text the first 6 to7 numbers are the registration numbers for the archived reports that are held at the BGS Edinburgh office (SO= Scottish Office; 89 = year received for archival; 123 = serial number of the report received that year). Other reports are archived in the BGS Keyworth office.

Reports listed in overall **bold** are those presented in Figure 6 and record internal evidence or lack of evidence for long-term sand bank migration to the east.

Appendix 2. Commercial site investigation reports reviewed

SO/89/130 1991 Rig Survey 49/24-R 31/08/90-03/09/90 Geoteam 1097.30 Shell UK Exploration & Production 1097.30. 53º 13.00'N - 53º 14.75'N 02º 37.00'E - 02º 40.00'E, east of **SWARTE BANK** Keywords: echosounder, sidescan sonar, boomer, seabed samples, sandwaves, mega ripples, NW migration of bedforms outside of main sand banks

SO/89/141 1985 Site Survey UKCS 43/18 Geoteam 0814.4 Total Oil Marine 0814.4 54º22'N - 54º29'N 01º 22'E - 01º 36'E, SW margin **DOGGER BANK**. Keywords: bathymetry, sidescan sonar, boomer, sandwaves, Bolders Bank Formation (diamicton) crop at seabed

SO/89/142 1986 Drilling rig site survey UK North Sea Block 44/23 Aquatronics 1855B Texas Gas Exploration (UK) Co 1855B. 54º11'N - 54º 14'N 02º 24'E - 02 27'E, OUTER **WELL BANK** Keywords: Quaternary and deeper geology, no seabed geology

SO/89/150 1988 North Sea - UK Sector Site Survey 44/22-7 Wimpol Conoco SO/89/150 54º 15.00'N - 54º 15.75'N 02º 14.50'E - 02º 15.5'E, **OUTER WELL BANK** Keywords: echosounder, sidescan sonar, 5kHz pinger, surface-tow boomer, multi-tip sparker, multi-channel high-resolution sparker, mega ripple patches, superficial sediment isopachytes, Bolders Bank Formation

SO/89/163 1988 site survey report proposed drillling site UKCS 48/3-DA Guardline Surveys Amerada Hess Ltd. 53º 56.5'N - 53º 57.7'N 01º 27.7'E - 01º 29.5'E, **WELL BANK FLAT** Keywords: echosounder, sidescan sonar, sub-tow boomer, sidescan sonar, multi-channel sparker, gravity corer, no maps

SO/89/165 1983 Geophysical and Bathymetric Survey Reports Palmer Marine Surveys 49/27-G-9200 Amoco (UK) Exploration Co 49/27-G-9200. 53º 02.25'N - 53º 03.16'N 02º 17.15'E - 02 23.00'E, SW **WELL BANK, LEMAN FIELD.** Keywords: echosounder, sidescan sonar, sub-tow boomer, multi-channel seismic reflection, magnetometer, sand bank, sound waves, internal sand bank reflectors, mega ripples

SO/89/166 1980 Platform Site Survey Job No. 49/26-E/1028 Guardline Surveys 49/26-E/1028 Shell UK Exploration & Production. 53º 02.5'N - 53º 03.5'N 02º 10.0'E - 02º 12.5'E, **LEMAN BANK**, NW flank Keywords: ripples, sandwaves, gravel lag, nb. 30m sand thickness

BGS Offshore Archive Report No. SO/89/167 1985 Site Survey Block 49/20 Geoteam 0814.5 Total Oil Marine 0814.5. 53º 17.00'N - 53º 22.00'N 02º 52.00'E - 03º 00.00'E, east of **NORFOLK BANKS** Keywords: boreholes to 30m below seabed, interpreted bathymetry and horizons only, shallow gas, echosounder, boomer, multi-channel seismic

SO/89/178 1982 Pipeline route survey Leman E to 49/26-BP Guardline Surveys Shell UK Exploration & Production 53º 03.00'N - 53º 05.00'N 02º 11.00'E - 02º 12.00'E, e) valley between southern **OWER AND LEMAN BANKS** Keywords: sidescan sonar, echosounder, 3.5 to 12 kHz pinger, interpretations only, ripples, trawl scars, smooth sandy seabed

SO/89/236 1988 Site Survey 49/22-5 Geoteam 1005.2 Conoco (UK) Ltd 1005. 53º 13.00'N - 53 13.75'N 02º 17.25'E - 02º 18.50'E, SW flank **BROKEN BANK** Keywords: echosounder, sidescan sonar, pinger, boomer, mini airgun, mega ripples

SO/89/238 1984 Survey report Palmer Marine Services Ltd 48/15A-D/0120 Conoco (UK) Ltd 48/15A-D/0120 Notes: a) Location of data (where archived): 53° 35.50'N 01° 57.50'E - 01° 59.50'E, sand banks, northern SWARTE BANK Keywords: echosounder, sidescan sonar, sub-tow , multi-electrode sparker, digital seismic system, shallow gas, stratification evidence for bank migration to E, sand banks, sand waves, mega ripples

SO/89/240 1984 Survey Report Palmer Surveys Ltd 48/15A-4/0128 Conoco (UK) Ltd 48/15A-4/0128 . 53° 29.50'N - 53° 30.50'N 01° 48.50'E - 01° 50.00'E. east of **COAL PIT.** Keywords: echosounder, sidescan sonar, pinger, sub-tow boomer, multi-electrode sparker, digital seismic system, mega ripples, gravel/boulder patches, relatively flat regional topography

SO/89/245 1987 Survey Report UK Block 44/22 Well Site 44/22-5 Palmer Surveys Ltd 0313 Conoco (UK) Ltd 0313 53° 13.75'N - 53° 14.5'N 02° 20.50'E - 02° 22.0'E, between **SWARTE AND BROKEN BANKS** Keywords: sidescan sonar, echosounder, boomer, multi-electrode sparker, multichannel seismic profiles, relatively flat meso topography, lithic/shell gravel patches

SO/89/247 1983 Survey Report Palmer Marine Surveys Ltd 49/16-PA/9166 Continental Oil Company Ltd 49/16-PA/9166. SW flank northern prolongation of **BROKEN BANK.** Keywords: echosounder, sidescan sonar, sub-tow boomer, multi-tip digital sparker profiler, sandwaves prograding over sand-ridges on sandbank

SO/89/248 1983 Survey Report Palmer Marine Surveys Ltd 49/16-PC/9166 Continental Oil Company Ltd 49/16-PC/9166 . 53° 22.5'N - 53° 23.5'N 01° 59.5'E - 02° 02.0'E, Area names: NW prolongation BROKEN BANK. Keywords: sand bank, sand waves, mega ripples, echosounder, sidescan sonar, multu-tip sparker, boomer, no internal structure in sand bank

SO/89/249 1984 Survey Report Palmer Marine Services Ltd 48/25B-A-9215 Conoco (UK) Ltd 48/25B-A-9215 . 53° 14.25'N - 53° 15.25'N 01° 58.00'E - 01° 59.5'E, e) Area names: between **INNER BANK AND WELL BANK**. Keywords: echosounder, boomer, multi-tip sparker, sidescan sonar, sand waves, sand bank

SO/89/250 1984 Survey Report Palmer Marine Surveys Ltd 49/21-7/9228 Conoco (UK) Ltd 49/21-7/9228. 53° 14.75'N - 53° 15.75'N 02° 00.00.50'E - 02° 01.75'E Area names: SW flank WELL BANK, adjacent to DTI P6 profile Keywords: echosounder, sidescan sonar, sub-tow boomer, multi-electrode sparker, high resolution multi-channel seismic mega ripples, no sandwaves, stratification of tilted seismic facies as evidence for bank migration to E

SO/89/251 1984 Survey Report Palmer Marine Surveys Ltd 48/25B-3 -9228 Conoco (UK) Ltd 48/25B-3 -9228 . Centre 53° 16.07'N 01° 56.87'E. Area names: between **WELL AND INNER BANKS** Keywords: no maps, examples of sidescan, boomer and multi-tip sparker only, mega ripples, sediment transport to SE, patches high reflectivity (gravel?) common between ripples crests

SO/89/256 1989 Survey Report Block 49/17-10 BritSurvey Conoco (UK) Ltd 53° 19.50'N - 53° 20.50'N 02° 13.00'E - 02° 14.25'E, e) Area names: Between **SWARTE AND BROKEN BANKS** Keywords: echosounder, sidescan sonar, sub-tow boomer, magnetometer, high resolution, multi-channel seismic

SO/91/042 1989 Site Survey Block 49/22-V BritSurvey Conoco (UK) Ltd. 53° 18.5'N - 53° 19.25'N 02° 14.5'N - 02° 16.00'E, Area names: NE flank BROKEN BANK Keywords: same area different results as SO/91/126, sandwaves, mega ripples, sandbank NE flank, peat, shallow gas in Quaternary above diapirs, echosounder, sidescan sonar, sub-tow boomer, high resolution multi-channel seismic. Compared to SO/91/126 elevation of overall bank topography different

on repeat surveys, with bank crest and small to very large transverse bedforms also displaced, but facing directions show migration of medium-large scale sand bedforms to SE consistent

SO/91/126 1990 Site Survey 49/22-V BritSurvey Conoco (UK) Ltd 53º 18.5'N - 53º 19.25'N 02º 14.5'E - 02º 16.00'E, Area names: NE flank BROKEN BANK Keywords: same area difference results as SO/91/042 sandwaves, mega ripples, sandbank NE flank, peat, shallow gas, echosounder, sidescan sonar, sub-tow boomer, high resolution multichannel seismic

SO/91/129 1990 Rig Site Survey 49/26 - Leman J 14/12/90-19/12/90 BritSurvey 13-260/349 Shell UK Exploration & Production 13-260/349. 53º 07.40'N - 53º 08.20'N 02º 01.50 - 02º 03.00'E, SW margin OWER BANK.Keywords: mega ripples, Bligh Bank Formation, Egmund Ground Formation, wreck, Leman Field, echosounder, sidescan sonar, boomer, multichannel high resolution seismic

SO/91/132 1989 Survey report proposed drilling site UKCS 49/22 Guardline Surveys Conoco (UK) Ltd. 53º 14.00'N - 53º 15.5'N 02º 21.50 - 02º 24.00'E, Area names: SWARTE BANK. Keywords: echosounder, sidescan sonar, boomer, high resolution multi-channel seismic, corer, magnetometer, Bligh Bank Formation, Yarmouth Roads Formation, sand waves, mega ripples, sand bank.

SO/92/007 1989 Site Survey Block 48/256-A BritSurvey Conoco (UK) Ltd 53º 18.00'N - 53 19.00'N 01º 56.00'E - 01º 57.00'E, Area names: WELL BANK Keywords: echosounder, sidescan, boomer, magnetometer, high resolution multichannel seismic, mega ripples, sand waves, sand bank

SO/92/011 1990 Survey Report proposed drilling site UKCS 48/20B Guardline Surveys Conoco (UK) Ltd. 53º 20.50'N - 53º 21.5'N 01º 50.00'E - 01º 51.25'E. Area names: west of northern prolongation of WELL BANK. Keywords: echosounder, sidescan sonar, boomer, UHR seismic reflection, magnetomer, gravity corer, mega ripples, sand waves on Botney Cut with sand muds and peat, Bolders Bank Formation, shallow gas

SO/92/016 1990 Well Site Survey UKCS Block 48/76 Marconi UDI Enterprise Oil. Centre 53º 44.95'N 01º 21.18'E , range 53º 44.00'N - 53º 46.00'N 01º 20.00'E - 01º 22.00'E. Area names: north of SOLE PIT. Keywords: echosounder, sidescan sonar, deep-tow sparker, high-resolution multi-channel seismic, grab samples, gravity core, mega ripples, sand waves

SO/92/040 1990 North Sea - UK Sector Site Survey 48/15B Wimpol Ltd Gas Council (Exploration) Ltd. 53º 37.00'N - 53º 39.30'N 01º 49.00'E - 01º 56.00'E. Area names: NE flank of SWARTE BANK prograded to east to cover part of the southern WELL HOLE. Keywords: Holocene, Bolders Bank Formation, shallow gas, sand waves, Swarte Bank Bank mobilising into adjacent closed basin, features that appear to be seabed pockmarks, echosounder, sidescan sonar, boomer, pinger, multichannel seismic

SO/92/054 1990 Exploration Site Survey Block 49/11b-JD BritSurvey Conoco (UK) Ltd. 53º 38.00'N - 53º 38.45'N 02º 03.50'E - 02º 05.00'E, between N. INDEFATIGABLE BANK and SWARTE BANK: echosounder, sidescan sonar, boomer, multichannel 'high-resolution' seismic, magnetometer, shipek, Indefatigable Ground Formation, Botney Cut Formation, Boulders Bank Formation, no 'mega ripples'.

SO/92/084 1985 Site Survey Report Racal Survey (UK) Ltd 44/22-3/5448A Conoco (UK) Ltd. Line joining 54º 16.40'N 02º 8.61'E and 54º 16.84'N 02º 37.62E, south of DOGGER BANK Keywords: high resolution multichannel, echosounder only, no beforms reported

SO/92/085 1985 Site survey report Racal Survey (UK) Ltd 48/150-4/5488 Conoco (UK) Ltd 48/150-4/5488. 53º 32.75'N 01º 57.75'E, Area names: SW margin **SWARTE BANK** Keywords: echsounder, sidescan sonar, boomer, multi-channel sparker, no data, no interpreted maps

SO/92/098 1991 Platform Site Survey Gawain GDB 21/07/91 - 26/07/91 Geoteam 1140.3 Shell UK Exploration & Production 1140.3. 53º 10.7'N 02º 39.15'E (centre), Area names: east of **SWARTE BANK** prolongation. Keywords: sidescan sonar, surface tow-boomer, echosounder, high resolution multi-channel, Holocene Sands, Swarte Bank, mega ripples only

SO/92/100 1991 Gawain Pipeline Route Surveys 25/07/91 - 06/08/91 Geoteam UK Ltd 1140.5 Shell UK Exploration & Production 1140.5. 53º 04.00'N - 53º 11.00'N 02º 30.00'E - 02º 45.00'E, Area names: east of **SWARTE BANK** prolongation. Keywords: Holocene, (Bligh Bank Formation), Elbow Formation, mega ripples only, sidescan sonar, echosounder, boomer, relatively flat regional topography

SO/92/110 1991 Rig Site Survey UKCS 43/15b-A BritSurvey Conoco (UK) Ltd. 54º 35.00'N - 54º 36.5'N 01º 53.50'E - 01º 55.3'E, Area names: **DOGGER BANK**, **SOUTH WEST PATCH**. Keywords: echosounder, sidescan sonar, parasound Beutch sub-bottom profiler, Holocene, Dogger Bank Formation, basal gravelly sands, top fine sands, patchy gravel in sand, tidal stream data, mega ripples

SO/92/135 1990 Site Survey Block 49/22-NN BritSurvey Conoco (UK) Ltd: 53º 16.00'N - 53º 17.5'N 02º 19.00'E - 02º 21.0'E: un-named bank between **BROKEN AND WELL BANKS** Keywords: sandbank, mega ripples, gravel, stringers, Yarmouth Roads Formation, echosounder, sidescan sonar, sub-tow boomer, magnetometer, multichannel seismic.

SO/93/072 1993 North Sea - UK Sector Site Survey 44/21-a-1 (F) Wimpol Conoco (UK) Ltd. 54º 13.50'N - 54º 14.5'N 02º 06.00'E - 02º 07.5'E: north of **OUTER WELL BANK**. Keywords: echosounder, sidescan, high resolution multichannel, Botney Cut, Boulder Bank Formation, isopachs Holocene Sands, . gravel on stiff clay of Bolders Bank Formations

SO/93/116 1992 Site Survey July-August 1992 UKCS 49/22-L Guardline Surveys Conoco (UK) Ltd.: 53º 17.50'N - 53º 20.00'N 02º 13.50'E - 02º 17.30'E, **BROKEN BANK,** NE flank. Keywords: echosounder, sidescan sonar, sub-tow boomer, magnetometer, high resolution seismic, ultra high resolution seismic, sandwaves, Broken Bank, interpreted data only

SO/94/1058 1994 Site Survey UKCS Location 48/29-X BritSurvey Phillips Petroleum Co (UK) Ltd. 53º 07.20'N - 53º 08.5'N 01º 40.00'E - 01º 43.00E, Block 48/29, south of **HADDOCK BANK**. Keywords: Echosounder, sidescan soner, 700 H_z- 7 kH_z parasound (TOPAS), Egmond Ground, NE axis sandwaves, interpreted data only, focus deep geology

SO/96/05 1996 platform site survey Galleon PG Geoteam-Wimpol M2015.2 Shell Exploration P96-146/02 Notes: 53º 29.00'N - 53º 31.00'N 01º 46.00'E - 01º 49.00'E. Blocks 48/14 and 48/15, NE of **COAL PIT.** Keywords: borehole data to 59.0m below seabed, Bolders Bank, Botney Cut Formation, swath bathymetry, sidescan sonar, boomer interpretation only, gravelly at crop of Bolders Bank Formation at seabed, 'megaripple' patches, otherwise patchy sand with boulders, poorly developed sandwaves

SO/96/06 1996 Galleon PG to Clipper PM Pipeline Route Survey Geoteam-Wimpol M2015.3 Shell (UK) Exploration & Production P96-146/03. 53º 27.5'N - 53º 32.0'N 01º 42.00'E - 01º 48'E: Blocks 48/14 and 48/19, **COAL PIT** NE to SW margin at **SWARTE BANK** Keywords: sidescan sonar, swath bathymetry, boomer, boreholes to 15m+, Bolders Bank Formation, mega ripples, sandwaves, closed basin

SO/97/28 1997 Ketch to Murdoch Pipeline route survey (vol. 1) Fugro-Geoteam M1019.1 Shell UK Exploration & Production Geosciences Services P97-146/03. 54º 03.00'N - 54º 16.1'N 02º 19.4'E - 02º 29.4'E, UK blocks 44/22 to 44/28, NW to **OUTER WELL BANK** Keywords: sidescan sonar, swath bathymetry, boomer, borehole to 43m+ below seabed, Well Hope Formation, muds, patchy ripples sand on gravel on Bolders Bank Formation

SO/97/310 1997 Cavendish Alpha Project Cavendish (UKCS 43/19) to Murdoch (UKCS 44/22) Pipeline Route Survey Guardline Surveys Amoco (UK) Exploration Co.: 54º 16.00'N - 54º 29.00'N 01º 46.00'E - 02º 20.00'E, NE of **OUTER WELL BANK** to **DOGGER BANK**. Keywords: no text, sidescan sonar, swath bathymetry, isolated depressions, Dogger Bank, Bolders Bank Formation, crops of high reflectivity, patches and sheets related to gravel and gravelly clay formations, in Bolders Bank and topographic highs

SO/98/32 1998 Jupiter Phase I Development Project UKCS 49/17-M(E+) Guardline Survey Conoco (UK) Ltd. 53º 23.5'N - 53º 24.5'N 02º 13.00'E - 02 15.00'E, NE flank **SWARTE BANK** Keywords: echosounder, swarth bathymetry, sidescan sonar, pinger, seabed bedforms not reported

SO/98/34 1997 Pipeline Surveys Blocks 49/23 - NW Bell to Bessemer UKCS Southern North Sea Seateam Amoco Exploration. 53º 11.66'N - 53º 12.60'N 02º 25.00'E - 02º 29.5'E, **SWARTE BANK**. Keywords: echosounder, swath bathymetry, sidescan sonar, pinger, boomer, 3m vibrocorer, 5m cone penetrometer, 'sandwaves', peat, shallow gas, nb. vertically-variable 'seabed' sediments

SO/2002/01 2002 Rig Site Survey Location UKCS 49/25 and Senn SW 18/12/01-03/01/02 Fugro Survey Ltd Shell Exploration. 1km^2 area centred on 53º 10.1'N 02º 52.04'E, Area names: east of **NORFOLK BANKS.** Keywords: boreholes, wells, bathymetry, foundation conditions, shallow gas survey data, Holocene, Eeem and Egmond Ground Formation, sand to 11m below seabed, mega ripples, single and multibeam echosounder, sidescan sonar, surface tow boomer, 10 cu in sleeve air gun, 3D seismic

SO/2001/25 2001 Rig Site Survey Barque P/H, UKCS block 48/14 Seabed Surveys (Fugro Survey Ltd) SSO 1005 Shell Exploration & Production. 53º 31.66'N - 53º 32.66'N 01º 41.66'E - 01º 43.33'E, Area names: NW of **COAL PIT**, SE of **SOLE PIT**. Keywords: Holocene, Botney Cut Formation, Bolder Bank Formation, Swarte Bank Formation, shallow gas, swath bathymetry, single-beam echosounder, sidescan sonar, gravity core data, sand waves, mega ripples, gravel on Bolders Bank Formation

Appendix 3 Scope of seabed data published in the BGS 1:250 000 scale seabed sediment maps southern SEA2

Regional maps and reports have been published by the BGS on SEA2 solid geology, Quaternary geology and seabed sediments. The maps are published at 1:250,000 scale and 1:1 million scale and cover the whole of the UK continental shelf. Each 1:250,000 scale map covers a rectangle of 1 degree latitude and 2 degrees longitude and is referred to by its designated name and the geographical coordinates of the south-west corner. The seabed sediment maps are compiled from the modified Folk (1954) classification of seabed sediments according to proportions of weight of particle size ranges.

1:250K map contents	California 54N 00E (1)	Silver Well 54N 02E (2)	Spurn 53N 00E (3)	Indefat-igable 53N 02E (4)	Flemish Bight 52N 02E (5)
Seabed sediment distribution and classification	Yes	Yes	Yes	Yes	Yes
Bathymetry, 10m contour interval	Yes	Yes	Yes	Yes	Yes
Tidal stream analyses	Yes	Yes	Yes	Yes	Yes
Holocene sediment thickness	No	Yes	No	Yes	Yes
Bedforms	Yes	No	Yes	Yes	Yes
Mean grain size sand fraction	Yes	Yes	Yes	Yes	Yes
Sorting sand fraction	No	No	Yes	Yes	No
Biogenic content gravel fraction	Yes	Yes	Yes	Yes	Yes
Carbonate content sand fraction	Yes	Yes	Yes	Yes	Yes
Carbonate content mud fraction	Yes	No	No	Yes	No

(1) Lott (1987)

(2) Jeffery *et al*, 1988

(3) Balson (1990)

(4) Harrison *et al*, 1987

(5) Cameron *et al*, 1984

Appendix 4 Survey types, equipment deployment and data acquired during the DTI SEA2 surveys in 2001

Appendix 4.1 Survey types and equipment deployment during the DTI SEA2 geophysical and sample surveys in 2001

Name of feature / transect	Station labels: sea bed photographs/video+samples (a) (shipboard examination, particle size analysis, geochemistry, macro-meio fauna, archival). For key to station labels assigned shipboard tied to BGS national archive sample numbers see Appendix 4.	Swath bathymetry (b)	Sidescan sonar (c)	Chirp profiler (d)
OWER BANK / P1 SERIES	P1A P1B P1C P1D P1E P1F P1G P1H P1.1A P1.1B P1.1C P1.1D P1.1E P1.1F P1.1G P1.1H P1.2A P1.2B P1.2C P1.2D P1.2E P1.2F P1.2G P1.2H P1.3A P1.3B P1.3C P1.3D P1.3E P1.3F P1.3G P1.3H P1.4A P1.4B P1.4C P1.4D P1.4E P1.4F			
SMITH'S KNOLL / P2 SERIES	P2A P2B P2C P2D P2E P2F P2G P2H			
INDEFATIGABLE BANKS / P3 SERIES	P3A P3B P3C P3D P3E P3F P3G P3H P3.1A P3.1B P3.1C P3.1D P3.1E P3.1F P3.1G P3.1H P3.2A P3.2B P3.2C P3.2D P3.2E P3.2F P3.2G P3.2H			
LEMAN BANK / P4 SERIES	P4A P4B P4C P4D P4E P4F P4G P4H P4.1 P4.1B P4.1C P4.1D P4.1E P4.1F P4.1G P4.1H			
HADDOCK BANK NORTH / P5 SERIES	P5A P5B P5C P5D P5E P5F P5G P5H P5I P5J P5K P5L P5M P5N			
WELL BANK / P6 SERIES	P6A P6B P6C P6D P6E P6F P6G P6H			
VIKING BANK / P7 SERIES	P7A P7B P7C P7D P7E P7F P7G P7H			
RACE BANK / P8 SERIES	P8B P8C P8E P8F			
HADDOCK BANK SOUTH / P9 SERIES	P9A P9B P9C P9D P9E P9F P9G P9H			
SW 0F SWARTE BANK / P10 SERIES	P10A P10B P10C P10D P10E P10F P10G P10H P10I P10J P10K P10L P10M			
BROKEN BANK / S1 SERIES	S1A S1B S1C S1D S1E S1F			
N SWARTE BANK / S2 SERIES	S2A S2B S2C S2D S2E S2F			
CROMER KNOLL S3 SERIES	S3A S3B S3C S3D S3E S3F			
INNER BANK /S4 SEREIS	S4A S4B S4C S4D S4E S4F S4G			
S SWARTE BANK / S5 SEREIS	S5A S5B S5C S5D S5E S5F			
COAL PIT / S7 SERIES	S7B S7C S7D S7E S7F S7G			
HAISBORO SAND / S8 SERIES	S8A S8B S8C S8D			
DOGGER BANK / DB SERIES	DBEA DBEB DBEC DBED DBEF DBEG DBEH DBEI DBEJ DBEJ2 DBEK DBEL DBWA DBWB DBWC DBWD DBWE DBWF DBWG DBWH DBWI DBWJ DBWK DBWL DBWM DBWN DBWO			

(a) Van Veen Grab: approximately 30x30cm jaw width, penetration to approximately10cm below seabed, sampled for seabed sediments from seabed to approximately 5cm below seabed. P = primary transect; S = secondary transect

(b) 111 beams 95kHz 2 degrees beam-width Simrad 100L multibeam echosounder data

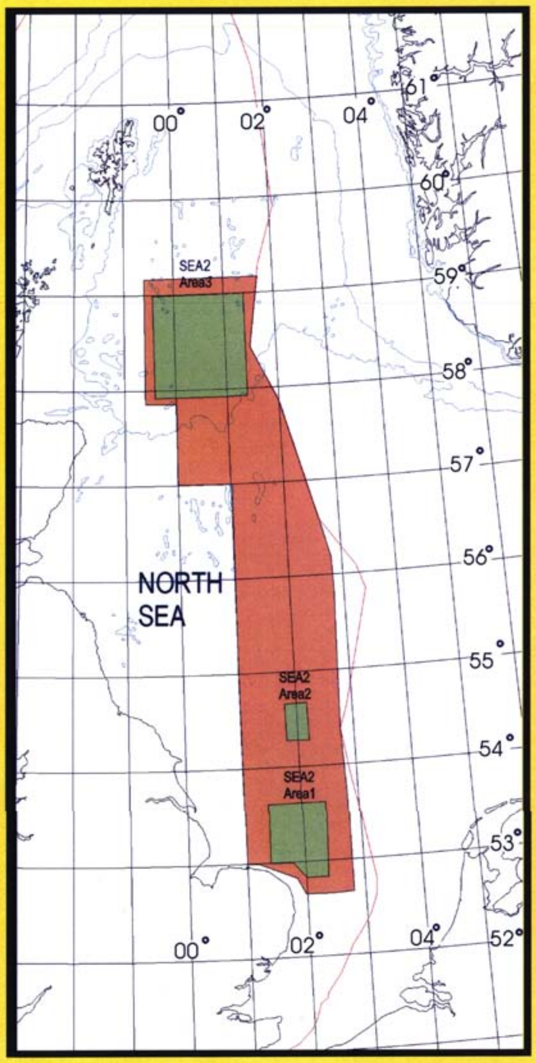
(c) 100/500kHz transceiver dual frequency Geoacoustics sidescan sonar data

(d) 7kHz Datasonics CAP600 Chirp II Acoustic Profiling System

(e) Precise navigation for ships underway geophysical surveys and ships dynamic positioning on photographic and sample sites was recorded and corrected in WGS84 using a DGPS system with an accuracy better than 1m.

4.2 Maps and discs recording the geophysical surveys

Maps and compact discs listed below are archived at BGS Edinburgh. They cover the northern (area 3) and southern SEA2 (areas 1 and 2). Area divisions were initially constructed for the 2001 program of geophysical data acquisition only. Thus the definition of the 3 areas (greyish-green areas, illustrated sketch map below) has been inherited from the original Geotek Ltd cruise planning and it has been retained for the descriptive consistency of this appendix. It predated the formal division of the UK sector into the 8 DTI SEA areas (frontispiece, this report).



Survey areas (green) DTI 2001
Strategic Environmental Assessment

SEA2-K-JACK: AREA 1

Map OV1: overview chart.
Map 1A: track chart.
Map 1B: bathymetry.
Map 1E: sub bottom profiler track chart.
Map 2A: track chart.
Map 2B: bathymetry.
Map 2E: sub bottom profiler track.
Map 3.1: track chart / bathymetry / seabed features / sidescan sonar mosaic / sub bottom profile.
Map 3.11: “ “ “ “ “
Map 4A: track chart.
Map 4B: bathymetry.
Map 4C: seabed features.
Map 4D: sidescan sonar mosaic.
Map 4E: sub bottom profiler track chart.
Map 5A: track chart.
Map 5B: bathymetry.
Map 5C: seabed features.
Map 5D: sidescan sonar mosaic.
Map 5E: sub bottom profiler track chart.
Map 6A: track chart.
Map 6B: bathymetry.
Map 6C: seabed features.
Map 6D: sidescan sonar mosaic.
Map 6E: sub bottom profilertrack chart.
Map 7A: track chart.
Map 7B: bathymetry.
Map 7E: sub bottom profiler track chart.

SEA2-K-JACK: AREA 2

Map OV2: overview chart.
Map 1.1: track chart / bathymetry /seabed features / sidescan sonar mosaic / sub bottom profile.
Map 1.11: “ “ “ “ “
Map 1:111: “ “ “ “ “
Map 1.1V: “ “ “ “ “
Map 1.V: “ “ “ “ “
Map 2A: track chart.
Map 2B: bathymetry.
Map 2C: seabed features.
Map 2D: sidescan sonar mosaic.
Map 2E: sub bottom profiler track chart.

SEA-K-JACK: AREA 3

Map OV3: overview chart.
Map 1A 1: track chart
Map 1A 11: track chart.
Map 1B 1: bathymetry.
Map 1B 11: bathymetry.
Map 1C 1: seabed features.

Map 7A 11: track chart.
Map 7B 1: bathymetry.
Map 7B 11: bathymetry.
Map 7C 1: seabed features.
Map 7C 11: seabed features.
Map 7D 1: sidescan sonar mosaic.
Map 7D 11: sidescan sonar mosaic.
Map 7E 1: sub bottom profiler track chart.
Map 7E 11: sub bottom profiler track chart.
Map 8A: track chart.
Map 8B: bathymetry.
Map 8b: bathymetry.
Map 8C: seabed features.
Map 8D: sidescan sonar mosaic.
Map 8E: sub bottom profiler track chart.
Map 9A: track chart.
Map 9B: bathymetry.
Map 9b: bathymetry.
Map 9C: seabed features.
Map 9D: sidescan sonar mosaic.
Map 9E: sub bottom profiler track chart.

SEA2-K-JACK: COMPACT DISCS.

1. Survey reports and daily logs.
2. Neptune screen dumps area 3.
3. Cfloor images area 1-3.
4. dxf-Files: box 1-9 overview, dxf-Files: detailed charts box 1-9, 1-2500.
5. dxf-Files: box 1-7 overview, plotfiles hpgl2: box 1-7 overview.
6. Mosaic box 1-2.
7. Mosaic box 1-8.
8. Processed chirp profiles (Bitumap) files 112-0312, 114-1348.
9. Processed chirp profiles (Bitumap) files 114-1431, 116-0017.
10. Processed chirp profiles (Bitumap) files 116-0029, 118-0043.
11. Processed chirp profiles (Bitumap) files 118-0101, 121-1854.
12. Processed chirp profiles (Bitumap) files 121-1913, 123-2339.
13. Processed chirp profiles (Bitumap) files 124-0010, 124-2022.
14. Plotfiles hpgl2: overview and box 6-9.
15. Plotfiles hpgl2, bathymetry detail 1:2500 (box1-9). Plotfiles: hpgl2, box 1-5.

SEA2-K-JACK: compact discs continued.

16. Dfx files: box 1 and 2. Plotfiles hpgl2: box1 and 2.
17. Processed MBES data (Ascii xyz Lat. Lon.).
18. Processed MBES data (Ascii xyz Lat. Lon.).
19. Processed MBES data (Ascii xyz Lat. Lon.).
20. Processed MBES data (Ascii xyz Lat. Lon.).
21. Processed MBES data (Ascii xyz Lat. Lon.).
22. Mosaic box 9 and Geotek logos.
23. Mosaic box 3, 4, 5 and 6.
24. Processed Chirp profiles (SEG-Y) files 112-0312, 112-1422.

25. Processed Chirp profiles (SEG-Y) files 112-1513, 113-0109.
26. Processed Chirp profiles (SEG-Y) files 113-0127, 113-1101.
27. Processed Chirp profiles (SEG-Y) files 113-1122, 114-0328.
28. Processed Chirp profiles (SEG-Y) files 114-0454, 114-1431.
29. Processed Chirp profiles (SEG-Y) files 114-1509, 115-0039
30. Processed Chirp profiles (SEG-Y) files 115-0119, 115-1107.
31. Processed Chirp profiles (SEG-Y) files 115-1137, 115-2317.
32. Processed Chirp profiles (SEG-Y) files 115-2329, 116-1437.
33. Processed Chirp profiles (SEG-Y) files 116-1448, 117-0129.
34. Processed Chirp profiles (SEG-Y) files 117-0227, 117-1510.
35. Processed Chirp profiles (SEG-Y) files 117-1537, 118-0142.
36. Processed Chirp profiles (SEG-Y) files 118-0158, 118-1127.
37. Processed Chirp profiles (SEG-Y) files 118-1145, 120-1553.
38. Processed Chirp profiles (SEG-Y) files 120-1631, 121-1514.
39. Processed Chirp profiles (SEG-Y) files 121-1534, 121-2337.
40. Processed Chirp profiles (SEG-Y) files 121-2355, 122-0720.
41. Processed Chirp profiles (SEG-Y) files 122-0838, 122-1448.
42. Processed Chirp profiles (SEG-Y) files 122-1527, 122-2350.
43. Processed Chirp profiles (SEG-Y) files 123-0029, 123-0850.
44. Processed Chirp profiles (SEG-Y) files 123-0942, 123-1546.
45. Processed Chirp profiles (SEG-Y) files 123-1629, 124-0330.
46. Processed Chirp profiles (SEG-Y) files 124-0357, 124-0918.
47. Processed Chirp profiles (SEG-Y) files 124-0939, 124-1734.
48. Processed Chirp profiles (SEG-Y) files 124-1753, 124-2022 + extra files.

Appendix 5 Southern SEA2 sample acquisition labels related to BGS archived sample registration numbers

DTI SAMPLE LABEL	BGS REGN NUMBER
P1.A	53 02 3094
P1.B	53 02 3021
P1.C	53 02 3022
P1.D	53 02 3023
P1.E	53 02 3024
P.1F	53 02 3025
P1.G	53 02 3095
P1.H	53 02 3096
P1.1A	53 02 3011
P1.1A	53 02 3012
P1.1B	53 02 3013
P1.1C	53 02 3014
P1.1D	53 02 3018
P1.1E	53 02 3019
P1.1F	53 02 3020
P1.1G	53 02 3097
P1.1H	53 02 3098
P1.2A	53 01 3601
P1.2B	53 01 3602
P1.2C	53 01 3603
P1.2D	53 01 3555
P1.2E	53 01 3556
P1.2F	53 01 3557
P1.2G	53 01 3604
P1.2H	53 01 3605
P1.3A	53 01 3536
P1.3B	53 01 3537
P1.3C	53 01 3538
P1.3D	53 01 3552
P1.3E	53 01 3553

P1.3F	53 01 3554
P1.3G	53 01 3606
P1.3H	53 01 3607
P1.4A	53 01 3539
P1.4B	53 01 3540
P1.4C	53 01 3541
P1.4D	53 01 3542
P1.4E	53 01 3543
P1.4F	53 01 3544
P2A	52 02 3201
P2B	52 02 3202
P2C	52 02 3203
P2D	52 02 3204
P2E	52 02 3205
P2F	52 02 3206
P2G	52 02 3207
P2H	52 02 3208
P3 A	53 02 3070
P3 B	53 02 3071
P3 C	53 02 3072
P3 D	53 02 3073
P3 E	53 02 3074
P3 F	53 02 3075
P3 G	53 02 3076
P3 H	53 02 3077
P3.1 A	53 02 3062
P3.1 B	53 02 3063
P3.1 C	53 02 3064
P3.1 D	53 02 3065
P3.1 E	53 02 3066
P3.1 F	53 02 3067
P3.1 G	53 02 3068
P3.1 H	53 02 3069

P3.2 A	53 02 3040
P3.2 B	53 02 3041
P3.2 C	53 02 3042
P3.2 D	53 02 3043
P3.2 E	53 02 3044
P3.2 F	53 02 3045
P3.2 G	53 02 3046
P3.2 H	53 02 3047
P3.2 I	53 02 3048
P3.2 J	53 02 3049
P3.2 K	53 02 3050

P4A	53 02 3009
P4D	53 02 3010
P4E	53 02 3026
P4F	53 02 3027
P4G	53 02 3101
P4H	52 02 3102

P4.1A	53 01 3533
P4.1B	53 01 3534
P4.1C	53 01 3535
P4.1 D	53 01 3558
P4.1 E	53 01 3559
P4.1 F	53 01 3560
P4.1G	53 01 3608
P4.1H	53 01 3609

P5 A	53 01 3568
P5 B	53 01 3569
P5 C	53 01 3570
P5 D	53 01 3571
P5 E	53 01 3572
P5 F	53 01 3573
P5 G	53 01 3574
P5 H	53 01 3575

P5 I	53 01 3576
P5 J	53 01 3577
P5K	53 01 3578
P5L	53 01 3579
P5M	53 01 3580
P5N	53 01 3581
P6A	53 02 3015
P6B	53 02 3016
P6C	53 02 3017
P6 D	53 02 3028
P6 E	53 02 3029
P6F	53 02 3030
P6G	53 02 3103
P6H	53 02 3104
P7 A	53 02 3051
P7B	53 02 3052
P7 C	53 02 3053
P7 D	53 02 3054
P7 E	53 02 3055
P7 F	53 02 3056
P7 G	53 02 3057
P7 H	53 02 3058
P7 I	53 02 3059
P7 J	53 02 3060
P8A	53 00 2222
P8B	53 00 2223
P8C	53 00 2224
P8D	53 00 2225
P8E	5300 2226
P8F	5300 2227
P9A	53 01 3544
P9B	53 01 3545
P9C	53 01 3546

P9D	53 01 3547
P9E	53 01 3548
P9F	53 01 3549
P9G	53 01 3550
P9H	53 01 3551
P10 A	53 02 3034
P10 B	53 02 3035
P10 C	53 02 3036
P10 D	53 02 3037
P10 E	53 02 3038
P10 F	53 02 3039
P10 G	53 01 3561
P10 H	53 01 3562
P10 I	53 01 3563
P10 J	53 01 3564
P10 K	53 01 3565
P10 L	53 01 3566
P10 M	53 01 3567
S1 A	53 02 3031
S1 B	53 02 3032
S1 C	53 02 3033
S1 D	53 02 3085
S1 E	5302 3086
S1 F	5302 3087
S2 A	53 01 3589
S2 B	53 01 3590
S2 C	53 01 3591
S2 D	53 01 3598
S2 E	53 01 3599
S2 F	53 01 3600
S3 A	53 01 3592
S3 B	53 01 3593

S3 C	53 01 3594
S3 D	53 01 3595
S3 E	53 01 3596
S3 F	53 01 3597
S4 A	53 02 3078
S4 B	53 02 3079
S4 C	53 02 3080
S4 D	53 02 3081
S4 E	53 02 3082
S4 F	53 02 3083
S4 G	53 02 3084
S5 A	53 02 3088
S5 B	53 02 3089
S5 C	53 02 3090
S5 D	53 02 3091
S5 E	53 02 3092
S5 F	53 02 3093
S7 A	53 01 3582
S7 B	53 01 3583
S7 C	53 01 3584
S7 D	53 01 3585
S7 E	53 01 3586
S7 F	53 01 3587
S7 G	53 01 3588
S8A	52 01 3251
S8B	52 01 3252
S8C	52 01 3253
S8D	52 01 3254
DBEA	54 02 457
DBEB	54 02 458
DBEC	54 02 459
DBED	54 02 460

DBEE	54 02 461
DBEF	54 02 462
DBEG	54 02 463
DBEH	54 02 464
DBEI	54 02 465
DBEJ	54 02 469
DBEJ2	54 02 466
DBEK	54 02 467
DBEL	54 02 468

DBW A	54 01 894
DBW B	54 01 895
DBW C	54 01 896
DBW D	54 01 897
DBW E	54 01 898
DBW F	54 01 899
DBW G	54 01 900
DBW H	54 01 901
DBW I	54 01 902
DBW J	54 01 903
DBW K	54 01 904
DBW L	54 01 905
DBW M	54 01 906
DBW N	54 01 907
DBW O	54 01 908

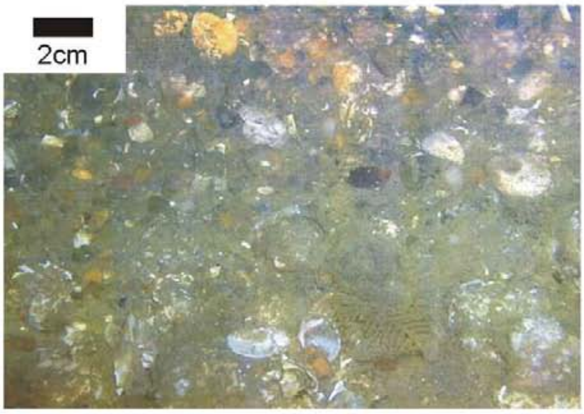
Appendix 6 Sample site photographs and grain size analyses

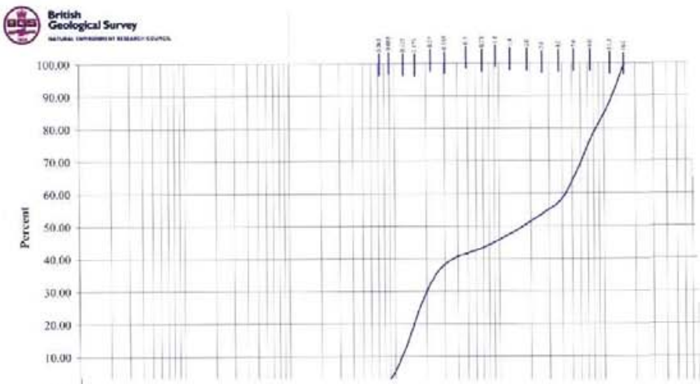
An example of hard copy showing the variety of data taken from 1 sample site on the digital database is illustrated on the next page. The seabed photographs are to scale.

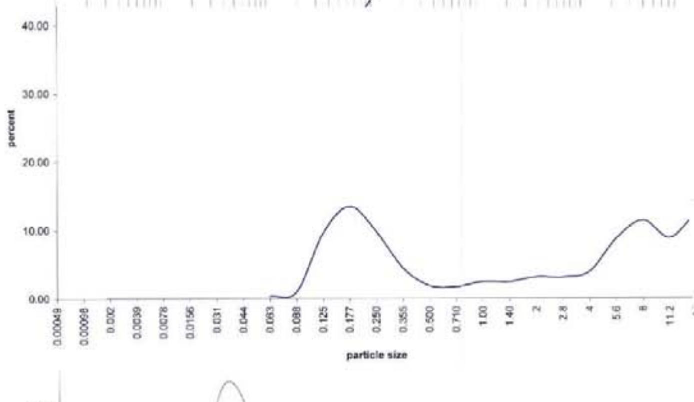
Access to the full digital dataset for 165 sample sites has not been possible for the MS Word version of this report.

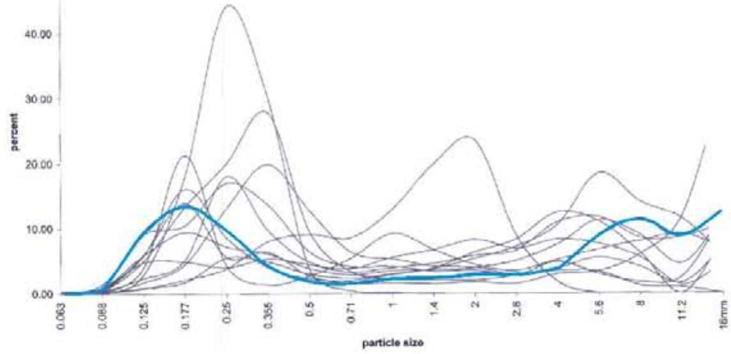
Access to the full digital dataset is possible through use of the links set up for the Adobe Acrobat (version 5) of this report. The links are set up on the list of stations shown under the figures showing the locations of the sample sites and graphs showing the variations of mean grain size and sample sorting with position across the banks.

Site P5C. Seabed photographs and sediment grain size analyses









Sample No. **P 5C**

	Weight	Percent
Gravel	202.00	51.74
Sand	183.20	46.93
Mud	5.20	1.33
Total	390.40	100.00

Grain size (mm)	Weight	Percent	Cumul Tot
0.00049			
0.00098			
0.002			
0.0039			
0.0078			
0.0156			
0.031			
0.044			1.33
0.063	1.20	0.31	1.64
0.088	3.80	0.97	2.61
0.125	37.40	9.58	12.19
0.177	52.50	13.45	25.64
0.250	38.20	9.78	35.43
0.355	17.40	4.46	39.88
0.500	7.20	1.84	41.73
0.710	6.60	1.69	43.42
1.00	9.50	2.43	45.85
1.40	9.40	2.41	48.26
2	12.20	3.13	51.38
2.8	12.00	3.07	54.46
4	15.40	3.94	58.40
5.6	34.10	8.73	67.14
8	44.60	11.42	78.56
11.2	34.60	8.86	87.42
16	49.10	12.58	100.00

Appendix 7 SEA2 technical report 008 – North Sea geology (August 2001)

This report is more than 60 pages long and has 10 figures. It is included within the hard copy and Adobe Acrobat forms of this report but not to the MS Word version.