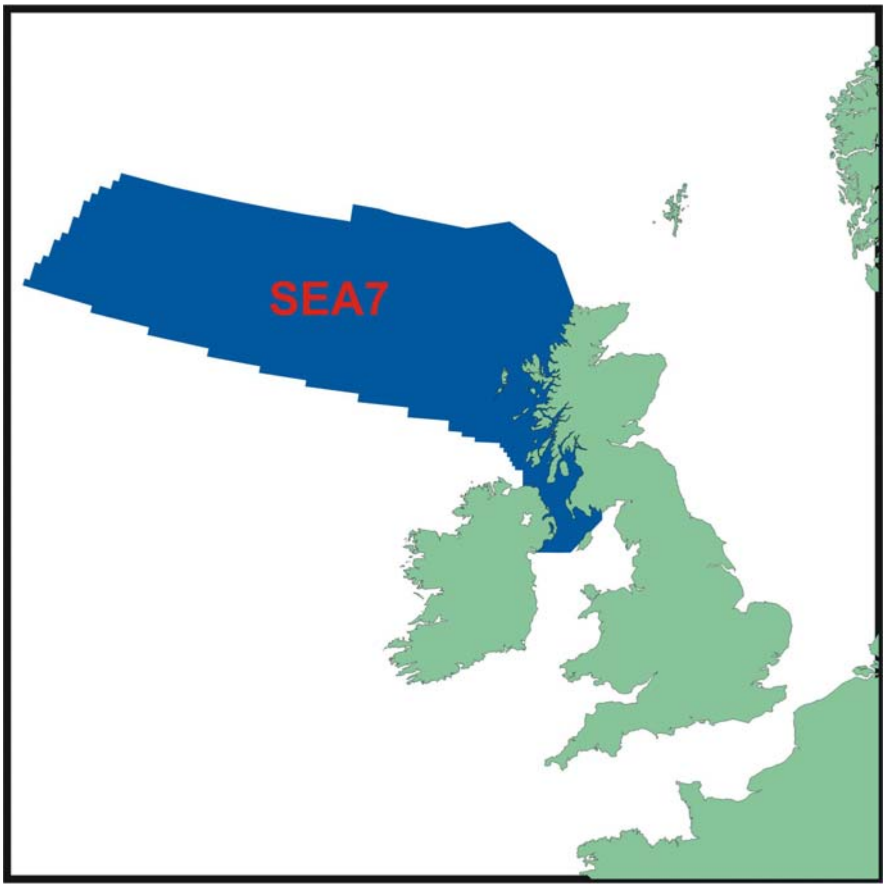
British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

DTI Strategic Environmental Assessment Area 7 (SEA7) Geological Metadata

Continental Shelf & Margins Programme

Commissioned Report CR/02/275



BRITISH GEOLOGICAL SURVEY

COMMISSIONED REPORT CR/02/275

DTI Strategic Environmental Assessment Area 7 (SEA7) Geological Metadata

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Foreword

This report is the published product of a study by the British Geological Survey (BGS) for research funded by the Department of Trade and Industry Offshore Environment and Decommissioning, Licensing and Consents Unit.

Acknowledgements

In addition to the authors and named contributors many other BGS staff have contributed to the metadata by providing references sourced from unpublished reports. These contributions are gratefully acknowledged.

Contents

1. Introduction

The Department of Trade and Industry Offshore Environment and Decommissioning, Licensing and Consents Unit (hereafter DTI) is responsible to the UK government for administering environmental legislation applicable to the oil, gas and renewable energy industry offshore. One such piece of legislation is EC Directive (2001/42/EEC). The EC Directive is generic and wide ranging 'on the assessment of the effects and certain plans and programs on the environment.' The activities regulated include seismic surveys, drilling, other seabed development operations and the decommissioning of offshore development structures. The programme of DTI Strategic Environmental Assessments is aimed at regional assessments of the possible impacts of offshore developments prior to new licensing rounds. The information from the strategic environmental surveys is therefore required to provide the technical basis on whether or not to grant commercial licences and consents for new offshore developments in the energy sector.

The objective of this research is to consider the scope of geological data that may contribute to the technical basis for the strategic environmental assessments:

1. Synopsis
2. Methods
3. Sources of metadata: scope, in terms of geography and type, where the original data is stored, the quality, issues of costs and licensing
4. Metadata

The area of study extends offshore from the coastlines of Scotland and Northern Ireland and across the NE Atlantic Ocean to the western limits of the UK exclusive zone (Figure 1). The seabed habitats are truly oceanic seawards of the shelfbreak and are currently within the category of frontier research areas.

The main part of this BGS report was completed in November 2002 and is supplemented by separately commissioned reports:

1. July 2003, the geological model for seabed mounds in the UK SEA7 and the Irish Sector (Unnithan,V. and Shannon, P. 2003. SEA7 Geology. *Report Marine and Petroleum Geology Research Group*. Dublin: Department of Geology, University College).
2. August 2003, summary of data that crosses the UK side of the SEA 6, 7 and 8 boundaries to approximately 50km within the Irish border (Wheeler, A. 2003. UK-Irish border public domain geological survey metadata. (Cork: University College, Department of Geology and Environmental Research)): inserted as Appendix 3 TAPPIN, D. R., WHEELER, A., ROWLANDS, K., JENKINS, G. AND SLATER, M. 2001. DTI Strategic Environmental Assessment Area 6 (SEA 6) Geological Metadata. *British Geological Survey*
3. *Commissioned Report*,CR/02/287. 17pp.

The reports listed above update some of the references compiled by the BGS in November 2002.

2. Synopsis

An inner physiographical zone extends seawards from a fjord-like coastline to encompass the continental shelf (mainly the Hebrides Shelf), the outer limit of which is defined by a shelfbreak in a range of approximately 140m to 400m or more water depth. An overall deeper-water middle physiographical zone includes the Rockall Trough, Rockall Bank and Rockall Plateau and smaller banks and seamounts such as the George Bligh Bank and Rosemary Bank. An outer physiographical zone includes the Hatton Bank, Endymion Spur and Maury Channel (Figure 2). The wide variety of the environments and the large area of SEA7 have more or less influenced the methodology used to compile the metadata (Section 3).

Prior to the 1980s many of the earliest publications useful to understanding the composition of seabed sediments and the processes forming the seabed sediments were derived from interpretations of single-beam topographic surveys, sidescan sonar images recorded on paper, single and multi-channel reflection seismic and core and grab sample surveys over the basin margins. The most intensive of the seabed surveys were in places where the oil-prospective rock formations crop or subcrop in relatively shallow water on the continental shelf. Subsequently, publications on seabed geology more or less accelerated with time with new development scenarios. These included more efficient ways of acquiring and processing survey data, the expansion of hydrocarbons, communications, fisheries, waste disposal, and defence activities, many extending to new deep-water environments. New agreements on the definition of exclusive national economic zones also contributed to the amount of offshore geological data collected. Increasing publication rates also originated from marine conservation research, some related to the development of tourism.

Some of the earliest UK seabed strategic research was initially funded by the Department of Energy and was completed in 1995 as part of the systematic regional BGS mapping and reporting programme to establish a geological framework for licensing and other development scenarios on the continental shelf and slope. Research for the exploitation of new and established resources continues. For example, there is increasing desire to develop the world-class potential in SEA7 for renewable (wind, wave) energy resources. The burgeoning diversity of development pressures on the environment has meant that measures for coastal and nearshore conservation areas are continuing, but that there are also new provisions for adoption of special areas of conservation in the deep-water environments (e.g. Darwin Mounds, NE Rockall Trough).

3. Methods

Appendix 2 summarises the network of those researchers who participated to review and input the data for this report.

Metadata outputs are in Endnote © version 6 format. For the bibliographic datasets Endnote files were compiled from BGS and SOC research with principal data merged or extracted from the GeoRef and the Geoarchive and Aslib online databases, the BGS regional offshore reports series, Western Frontiers Association bibliography compiled in ACCESS format, Stratagem (EU OMARC project cluster) and other publications in MS word. Online geological searches were linked to geographical keywords (Appendix 3). The bibliographic search was completed in November 2002. The breakdown of the geological/geophysical search categories is further explained in Section 4 below.

Maps are considered essential report outputs where the Endnote © format is unsuitable for clearly illustrating the geographical extent, density or interrelationships of the metadata. This is particularly pertinent to the deep-water and remote regions where much of the seabed habitat is unexplored or patchily reconnoitred. Maps were thus derived from information stored in BGS files in ARCVIEW, ORACLE-GMT and ACCESS formats and from geographical coordinates of the regional geophysical data supplied by the Southampton Oceanography Centre. The BGS offshore science GIS database covers the whole UK zone. The regional metadata from the various sources were clipped to fit the area of SEA7 and output as a series of thematic maps for this report.

To accord with the contract, this report is output in hard-copy and compact disc formats.

4. Sources of metadata

Non-bibliographic

The information in this section has been presented in map form for the reasons explained in Section 3 above.

There are licensing or copyright issues for raw and processed profile and plan data (e.g. Hydrographic Office sonar and bathymetric data) and with interpreted data perhaps with intellectual property rights attached (e.g. BGS digital bathymetry, seabed sediment and geochemical data). Sources of metadata in both the ownership and geographical sense have been merged into the figures. Further explanations of the figures and/or the metadata links are given in the text below the figure titles.

In the following reference has been made to the generic link www.bgs.ac.uk whereas specific offshore data can be accessed at http://www.bgs.ac.uk/discoverymetadata/home.html .

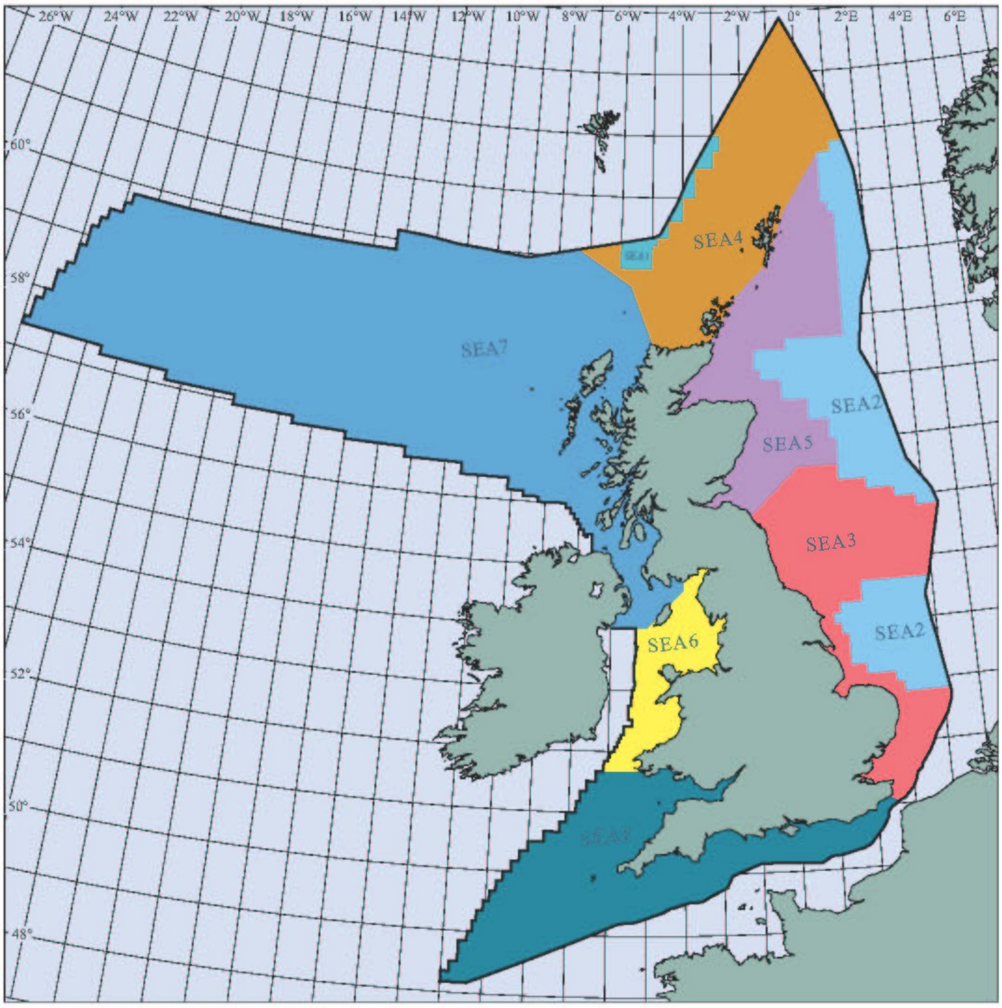

Figure 1. DTI UK Strategic Environmental Assessment areas www.offshore-sea.org.uk

The UK zone is organised into 8 SEA areas. Aside from geology the reports for these incorporate aspects of habitat biotope, hydrography and chemistry the details of which are identified within the DTI-funded website for the programme managed by Geotek Ltd www.offshore-sea.org.uk

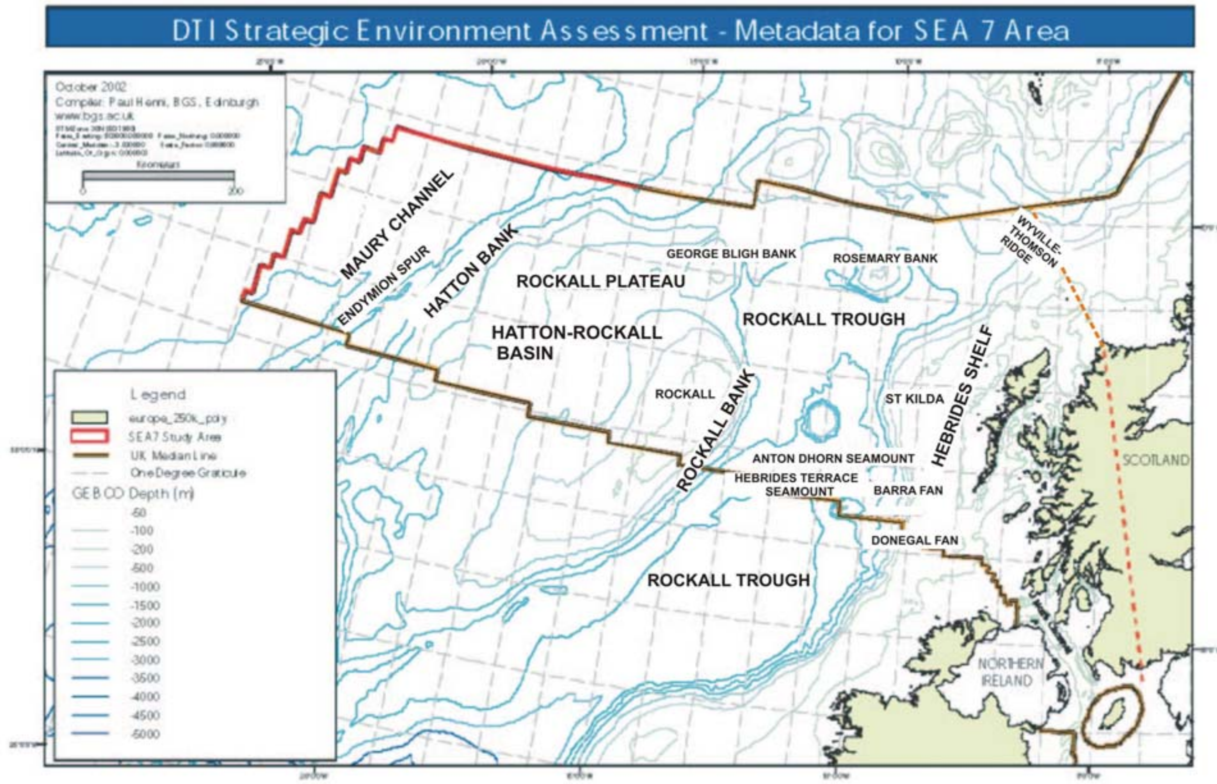

Figure 2. Physiography and selected geographical names

www.bodc.ac.uk/projects/gebco97.html

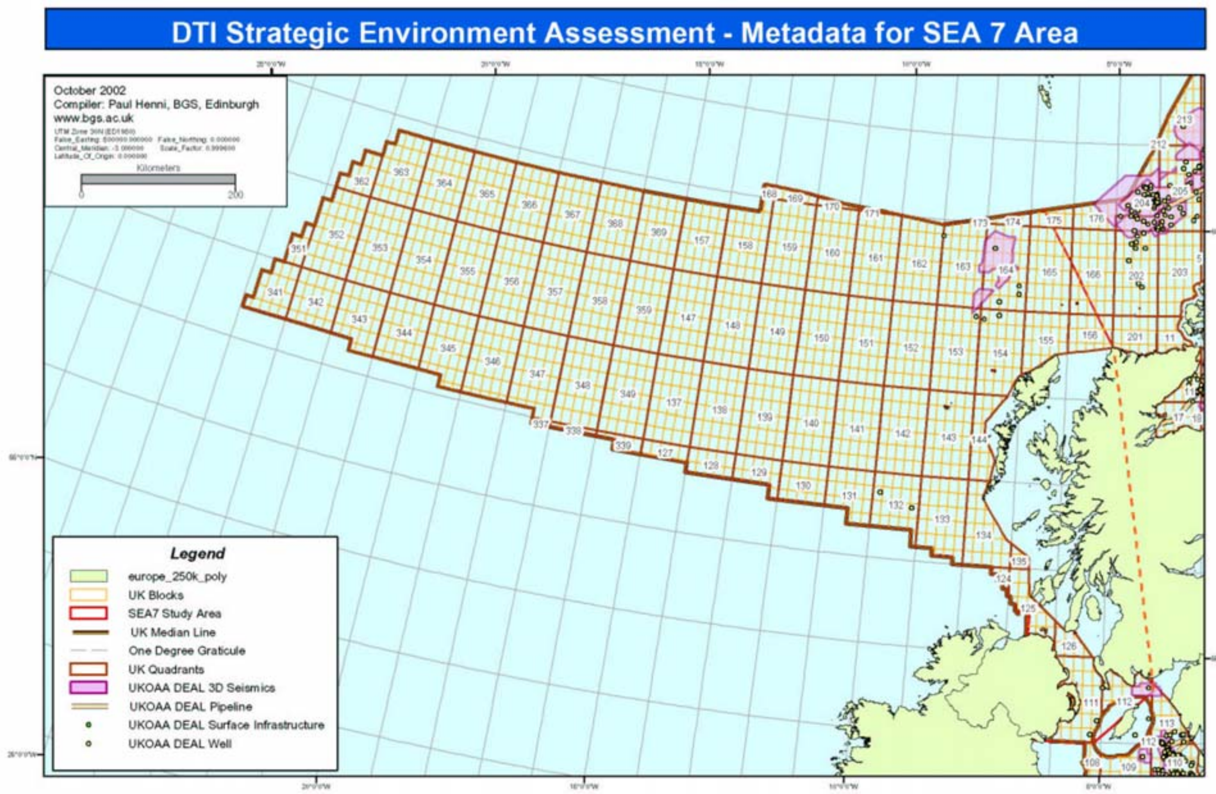

Figure 3. Oil exploration infrastrucure

Aspects of development infrastructure and the availability of commercial hydrocarbons exploration and development data for the UK zone are incorporated into the DEAL programme managed by UKOOA for BGS. www.ukdeal.co.uk

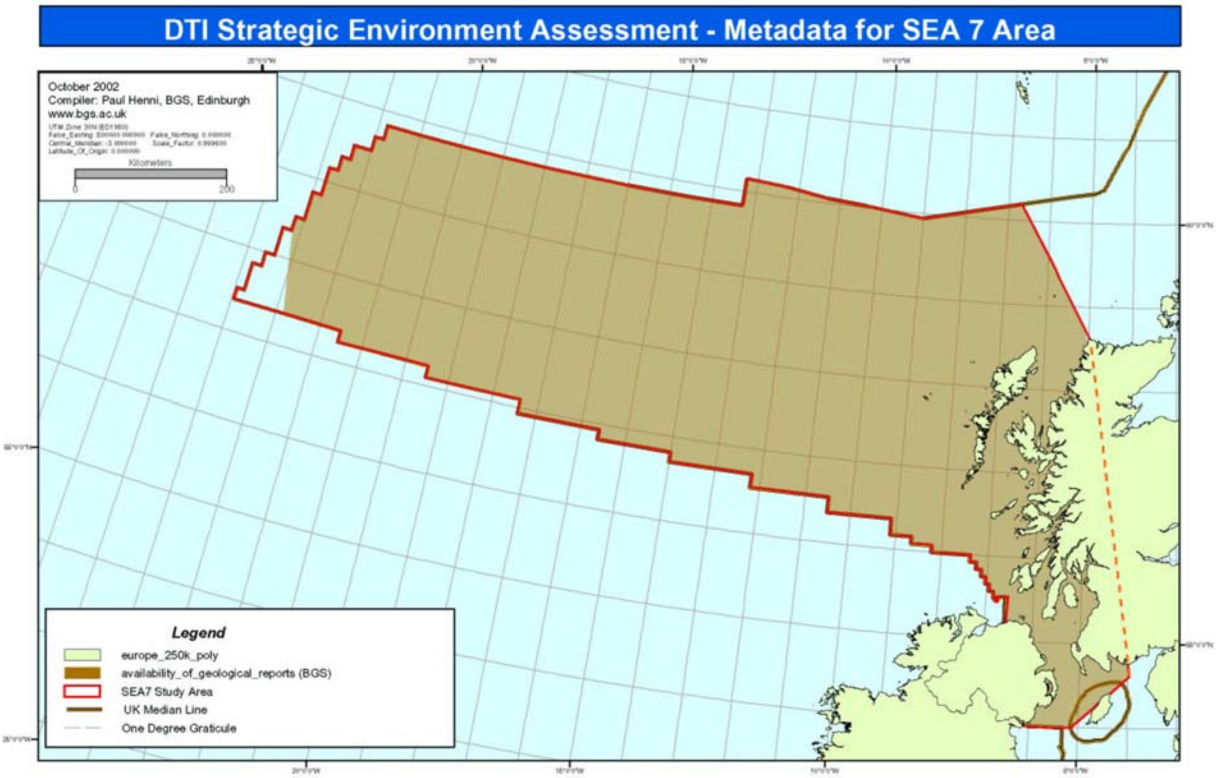

Figure 4. Unpublished geological reports www.bgs.ac.uk

Figure 4 is derived from the Oracle database: Non-confidential BGS reports or reports likely to be released without charge into the public domain (grey literature). The data include some WFA bibliography and other dedicated databases as appropriate.

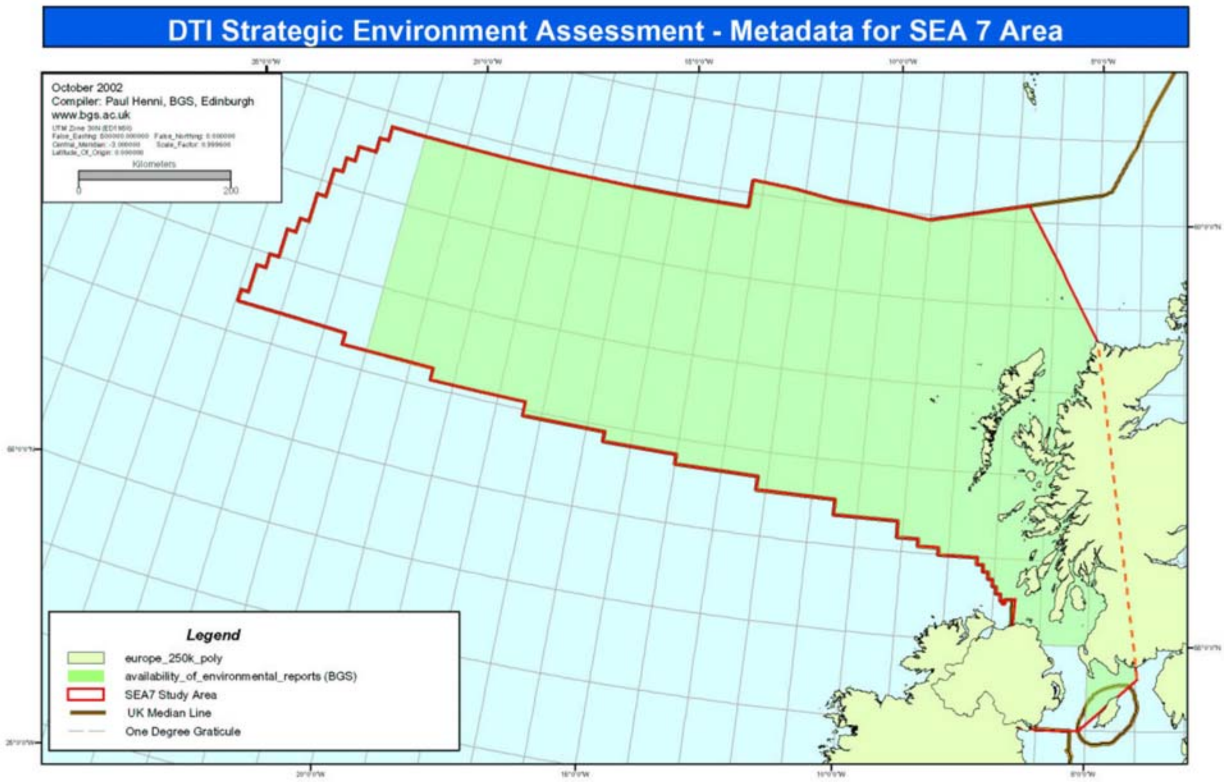

Figure 5. Unpublished environmental reports www.bgs.ac.uk

Figure 5 is derived from the Oracle database and shows the potential scope for non-confidential BGS reports describing environmental aspects of the seabed and shallow sub-surface.

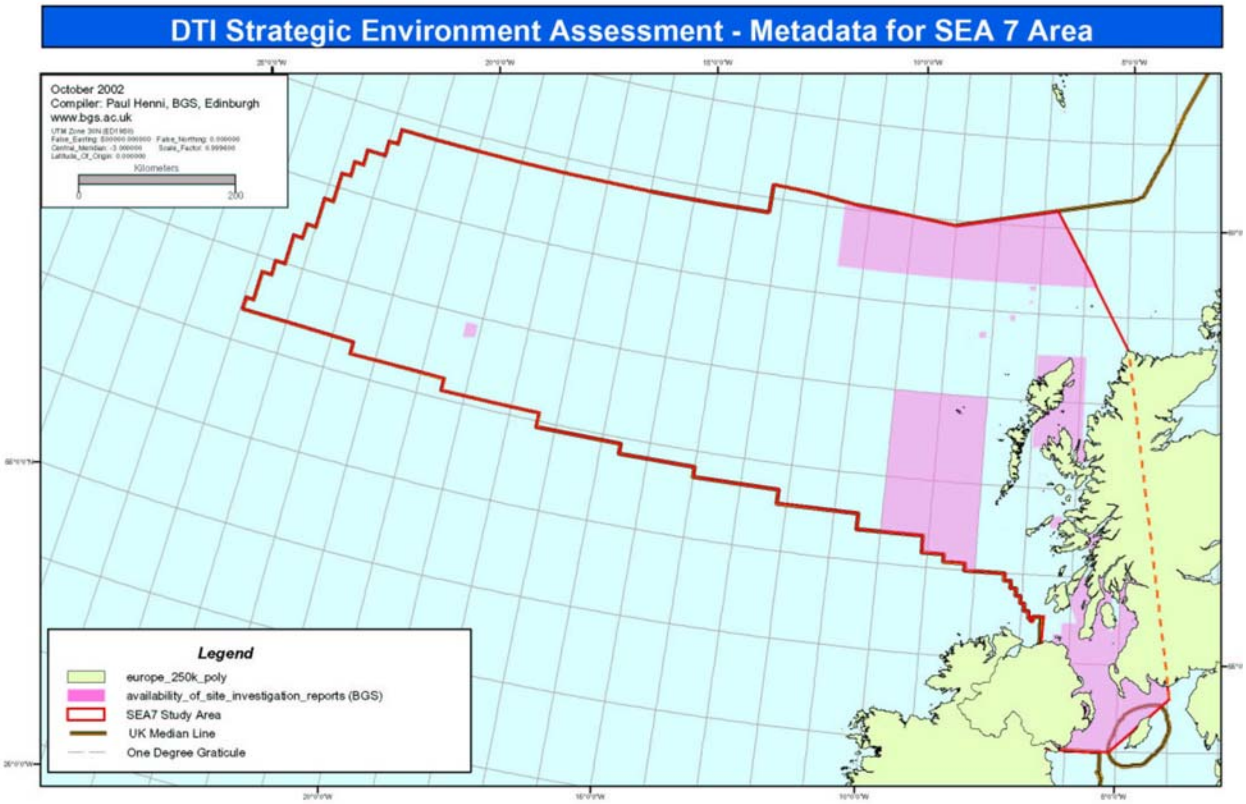

Figure 6. Unpublished Site investigation reports www.bgs.ac.uk

The BGS Oracle Database contains reports describing the geology and geotechnics of specific sites related to drilling and civil engineering. These are currently archived in the BGS as area polygons with no indication of content and have been registered with the BGS following UKOOA recommendations. There is currently (November, 2002) no method of retrieving the detail of the quality and content of these reports without retrieving them as the hard-copy report or, more recently, as CDs. Well site investigations: these would typically consist of a 3x3 or 1x1km area surveyed with single or multi channel mini-sleeve/air gun, sparker, pinger / boomer / echosounder / sidescan sonar, with some interpretation calibrated by core. More problematic deep-water site investigations may have employed seabed photography, some with Autonomous Underwater Vehicles. The release of most of this data would require the commercial owners permission and the reports very rarely contain the raw datafiles used by the contractor.

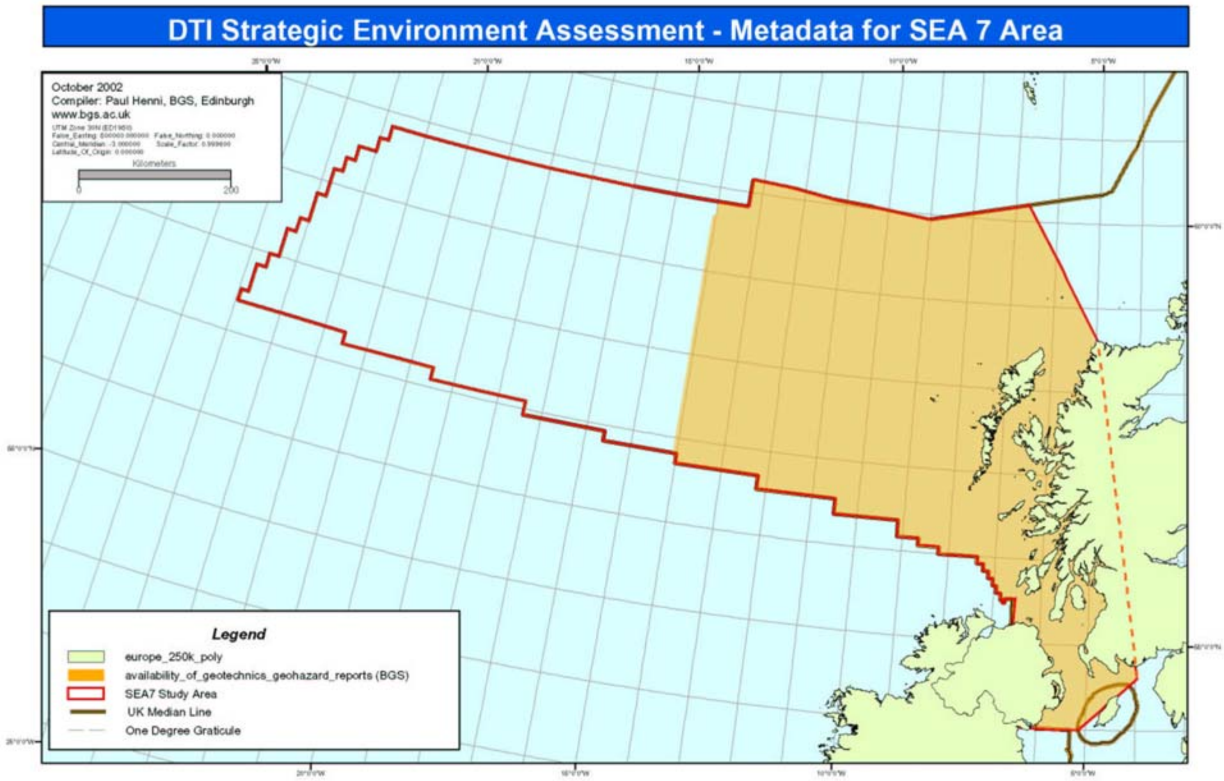

Figure 7. Unpublished geotechnics/geohazards reports www.bgs.ac.uk

Oracle Database: Reports describing the geology and geotechnics of specific sites or larger areas

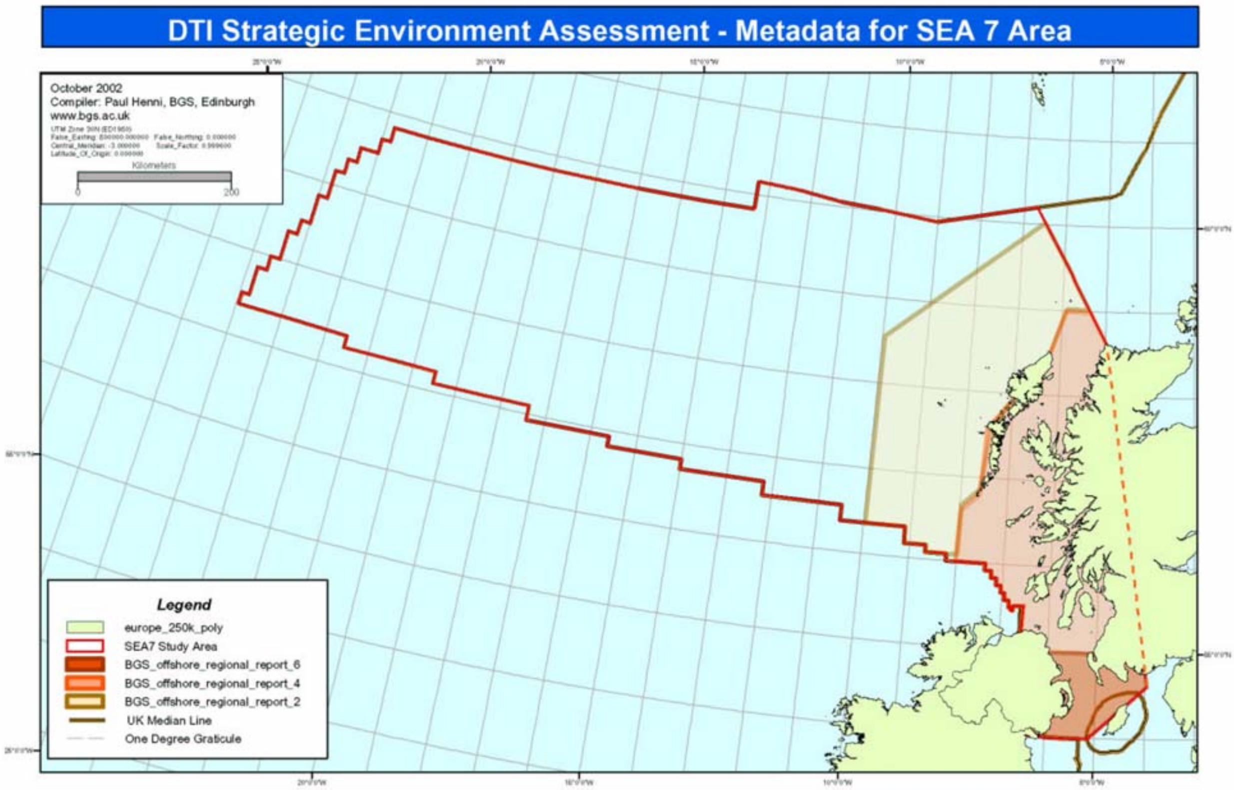

Figure 8. Published offshore regional reports www.bgs.ac.uk

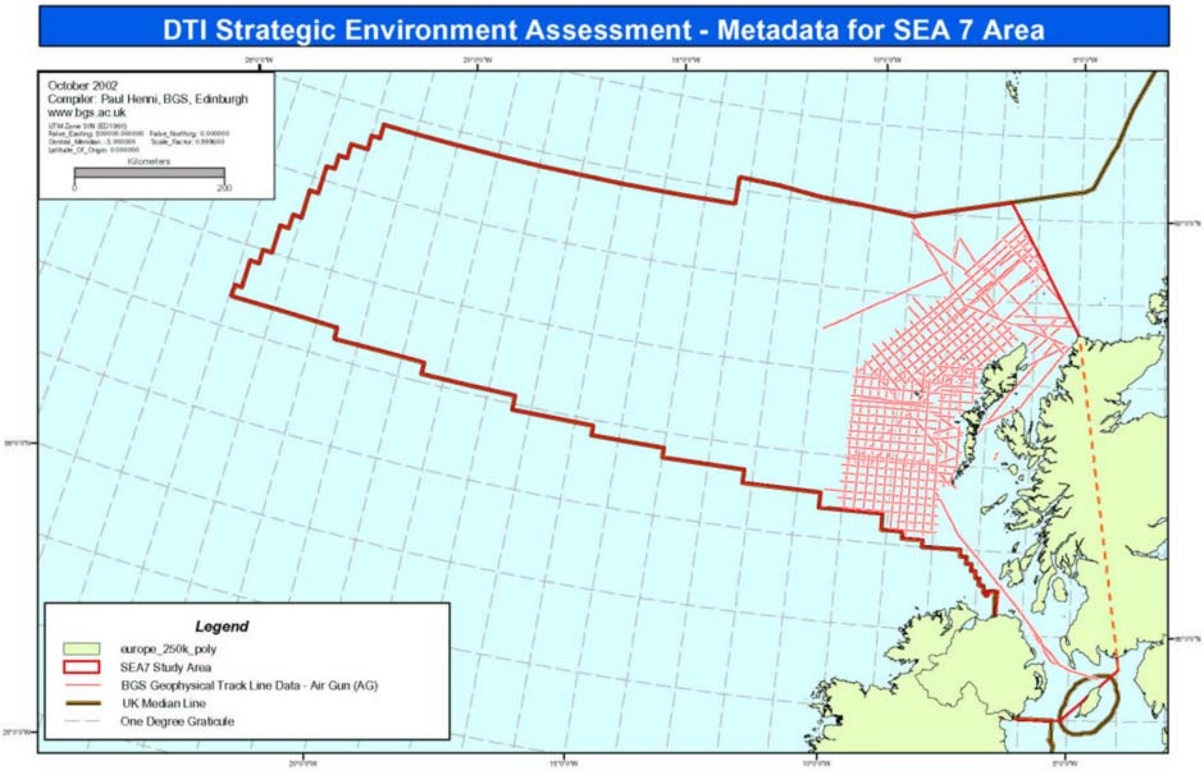

Figure 9. Regional survey: single channel air gun www.bgs.ac.uk

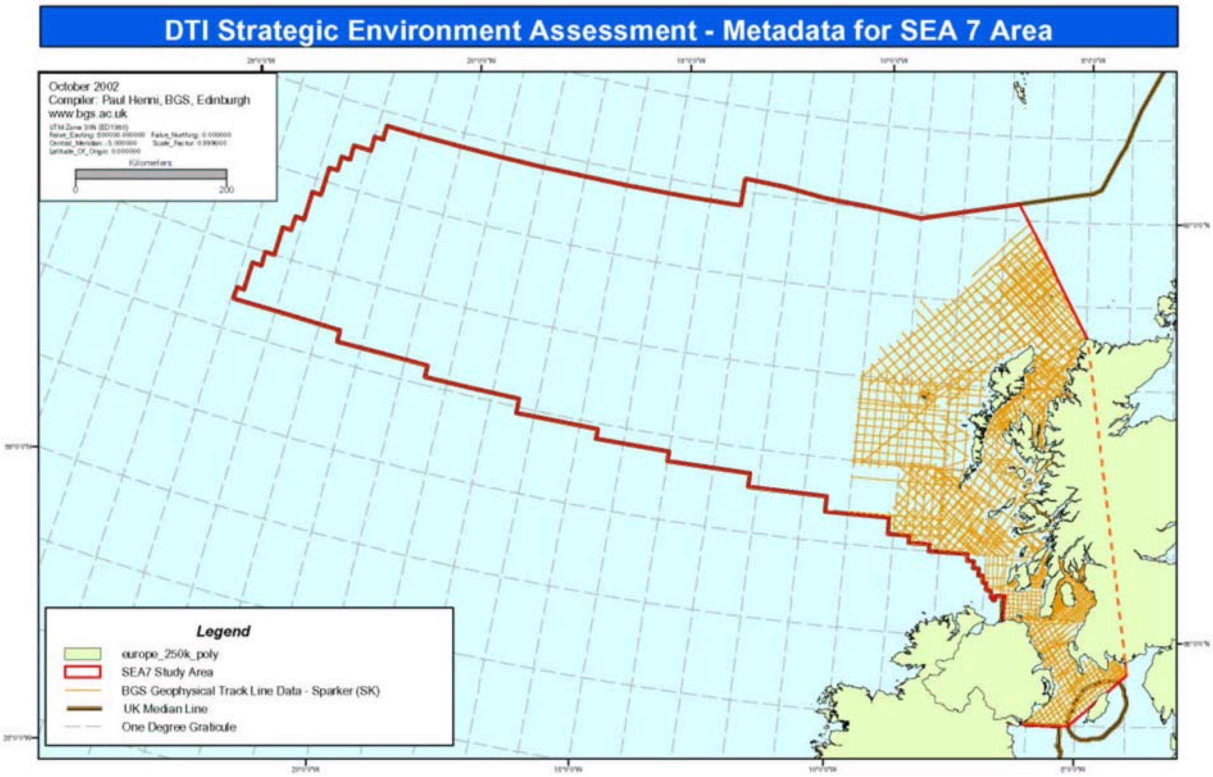

Figure 10. Regional survey: single channel sparker www.bgs.ac.uk

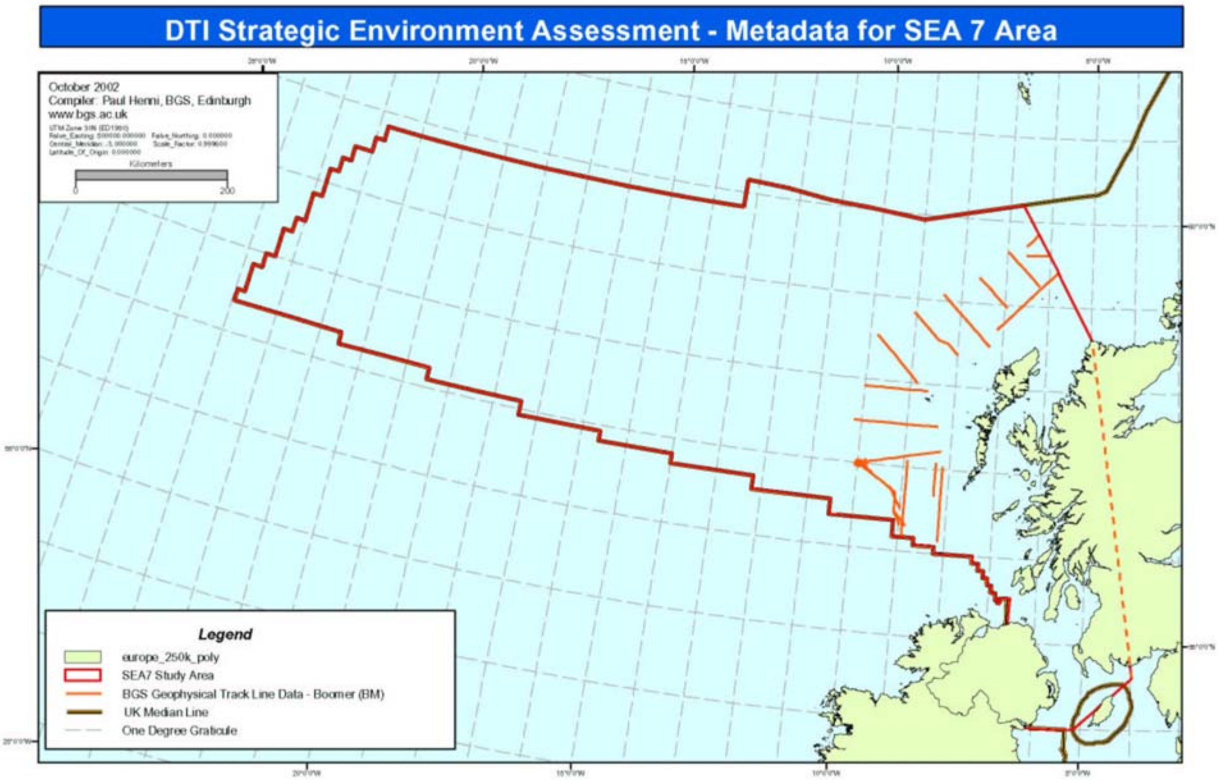

Figure 11. Regional survey: boomer www.bgs.ac.uk

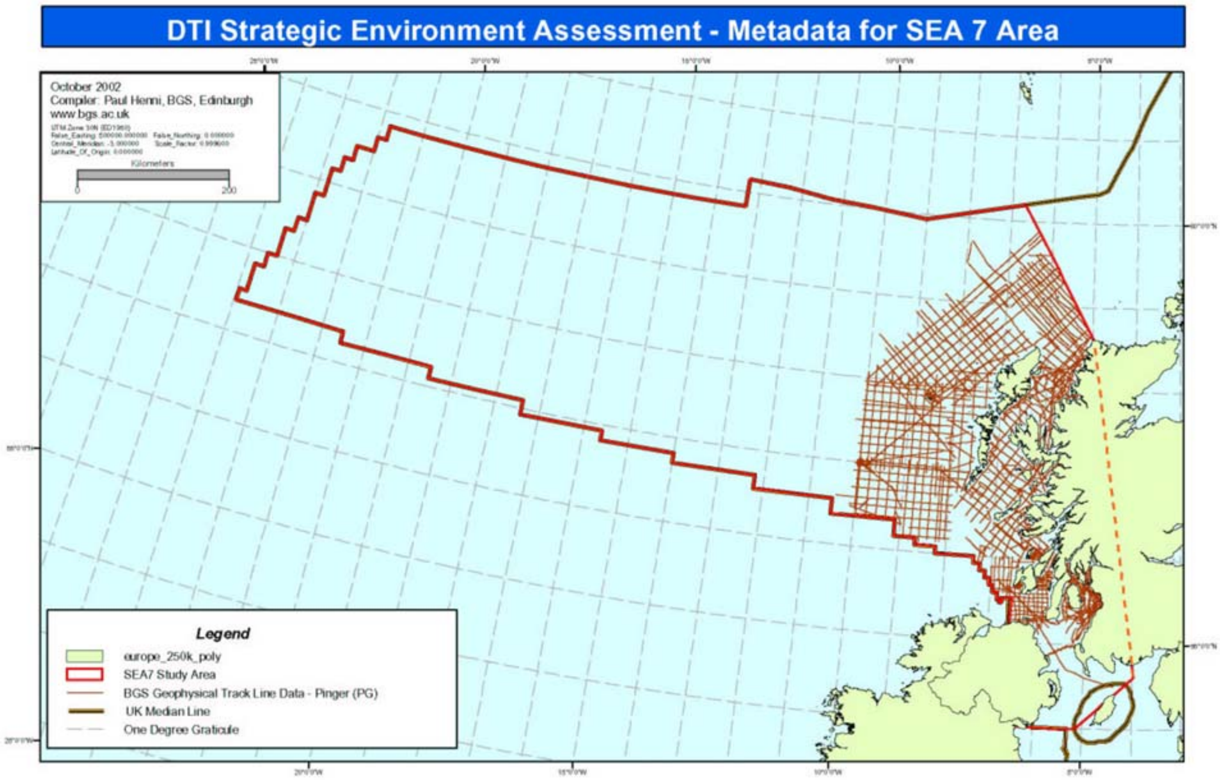

Figure 12. Regional survey: pinger www.bgs.ac.uk

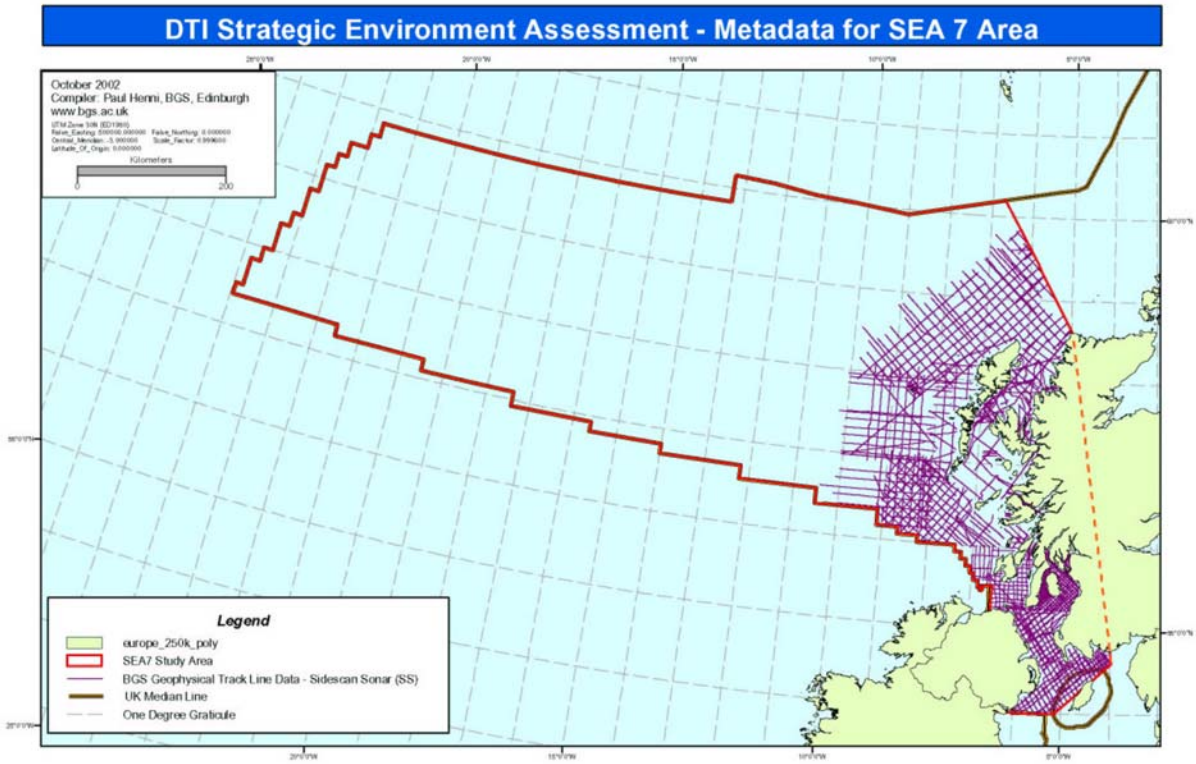

Figure 13. Regional survey: sidescan sonar www.bgs.ac.uk

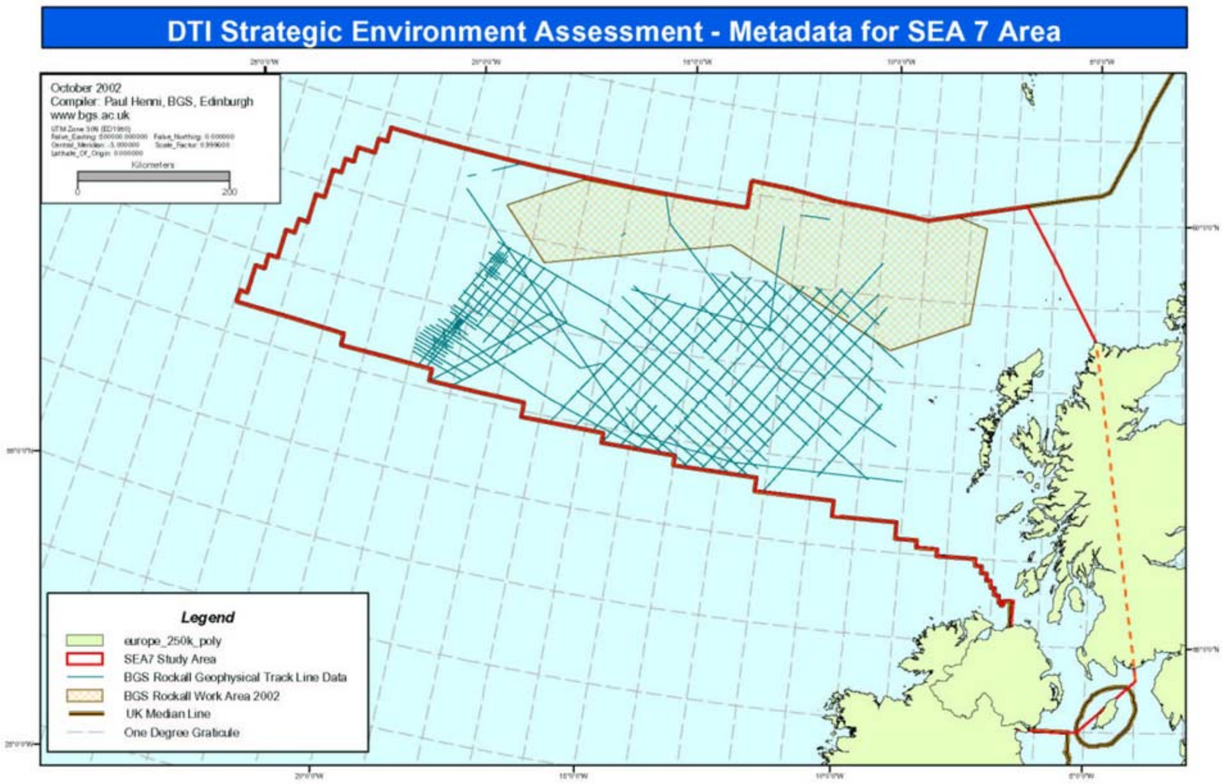

Figure 14. BGS Rockall Consortium: regional surveys www.bgs.ac.uk

Mainly single channel airgun with various combinations of high resolution reflection seismic but excluding sidescan sonar.

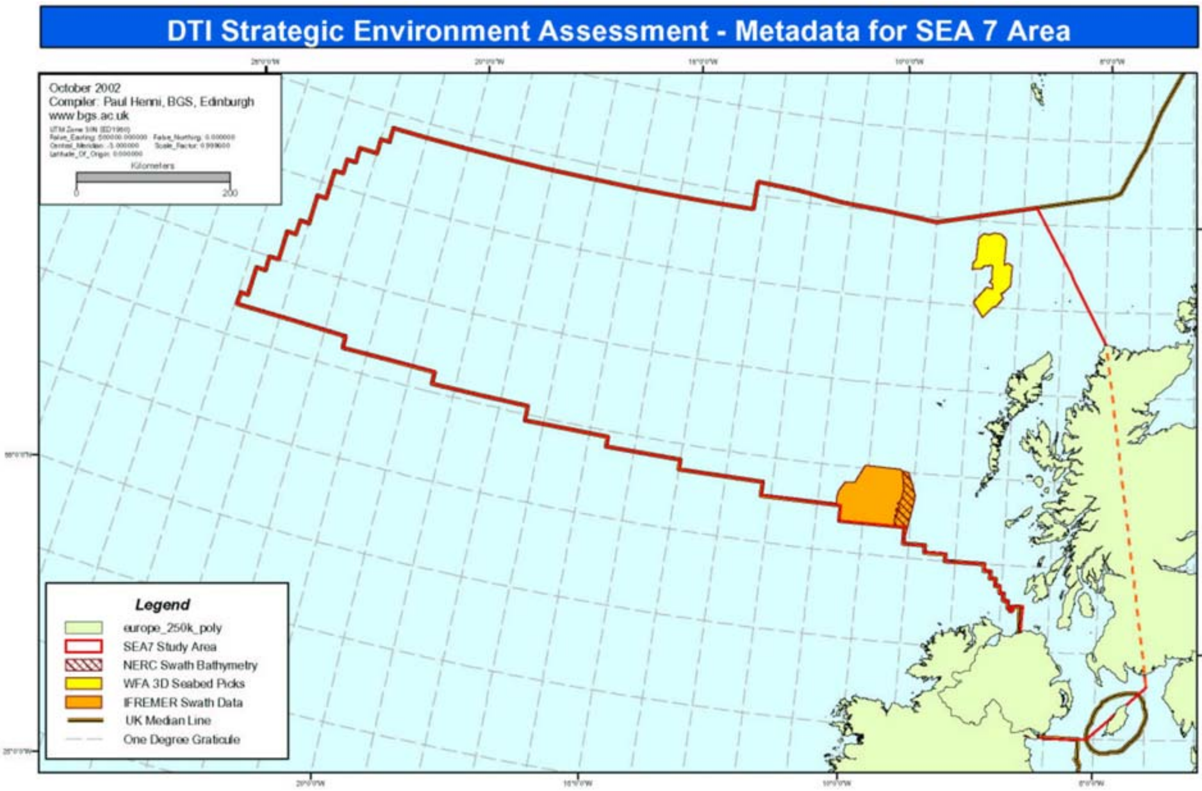

Figure 15. NERC and IFREMER multibeam survey, WFA 3D seabed picks www.bgs.ac.uk www.ifremer.fr

The NERC acquired data originate from the Land Ocean Interaction/ Shelfedge study. IFREMER-Regional surveys of swath bathymetry and seabed backscatter are related to deep-water fisheries research. BGS created images of shaded relief by processing seabed picks from 3D commercial seismic exploration surveys on behalf of the Western Frontier Association.

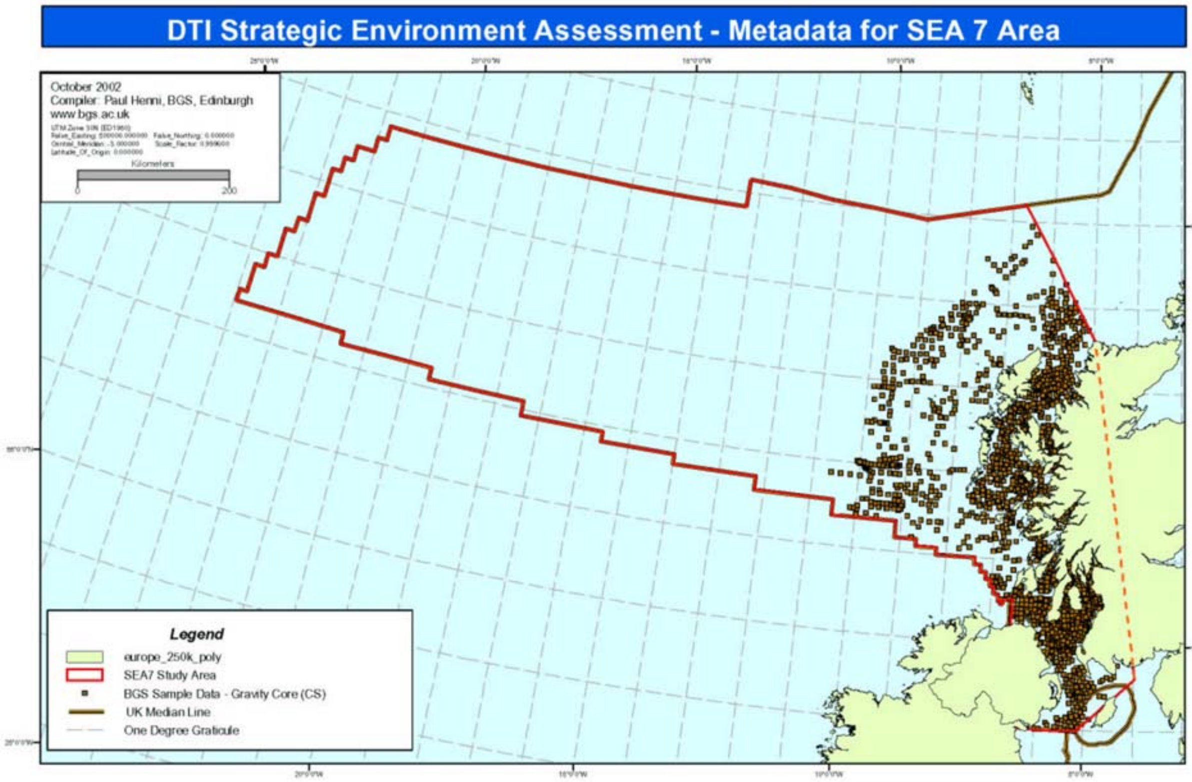

Figure 16. BGS gravity core sites *www.bgs.ac.uk*

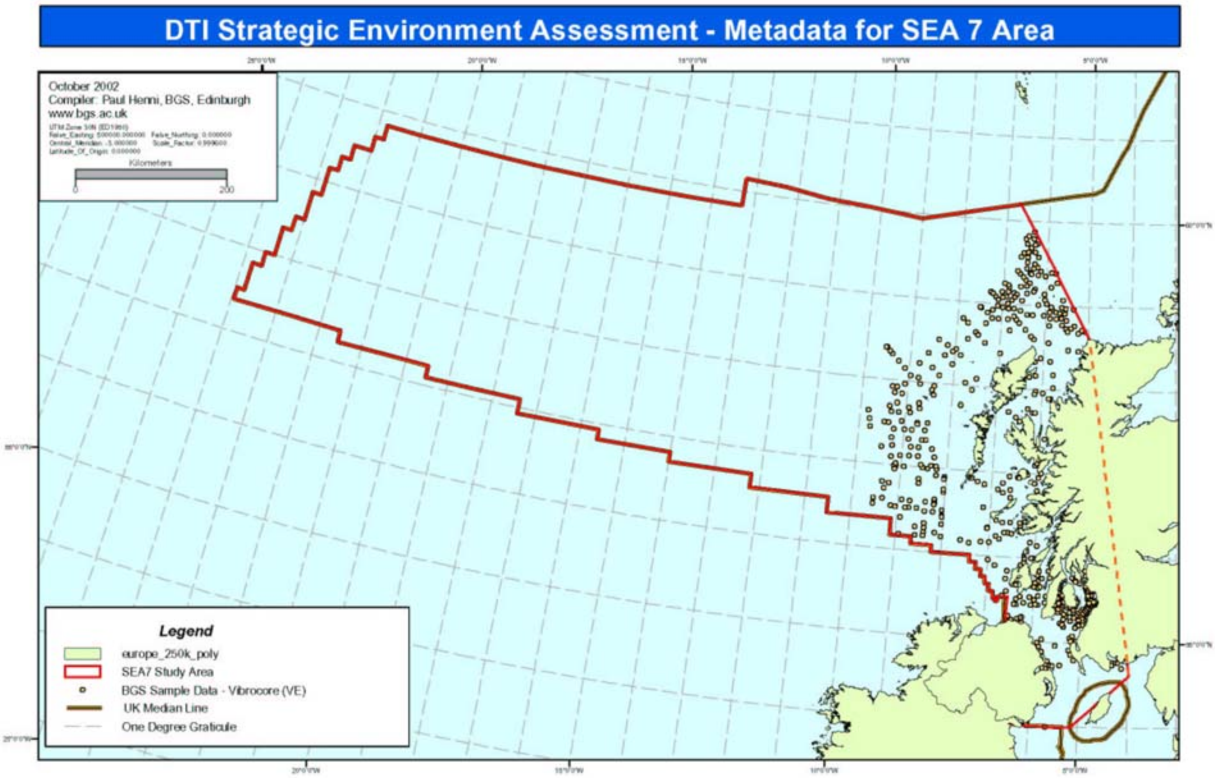

Figure 17. BGS vibrocore sites www.bgs.ac.uk

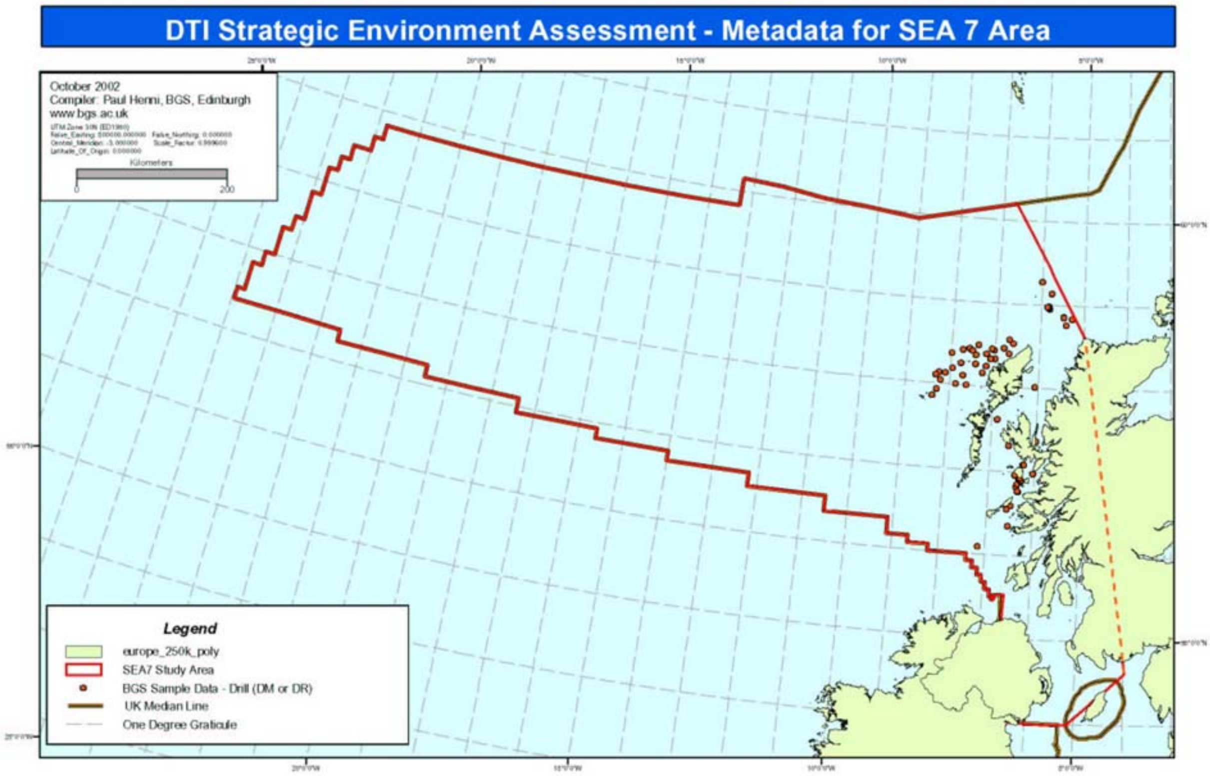

Figure 18. BGS 1m/5m rockdrill sites www.bgs.ac.uk

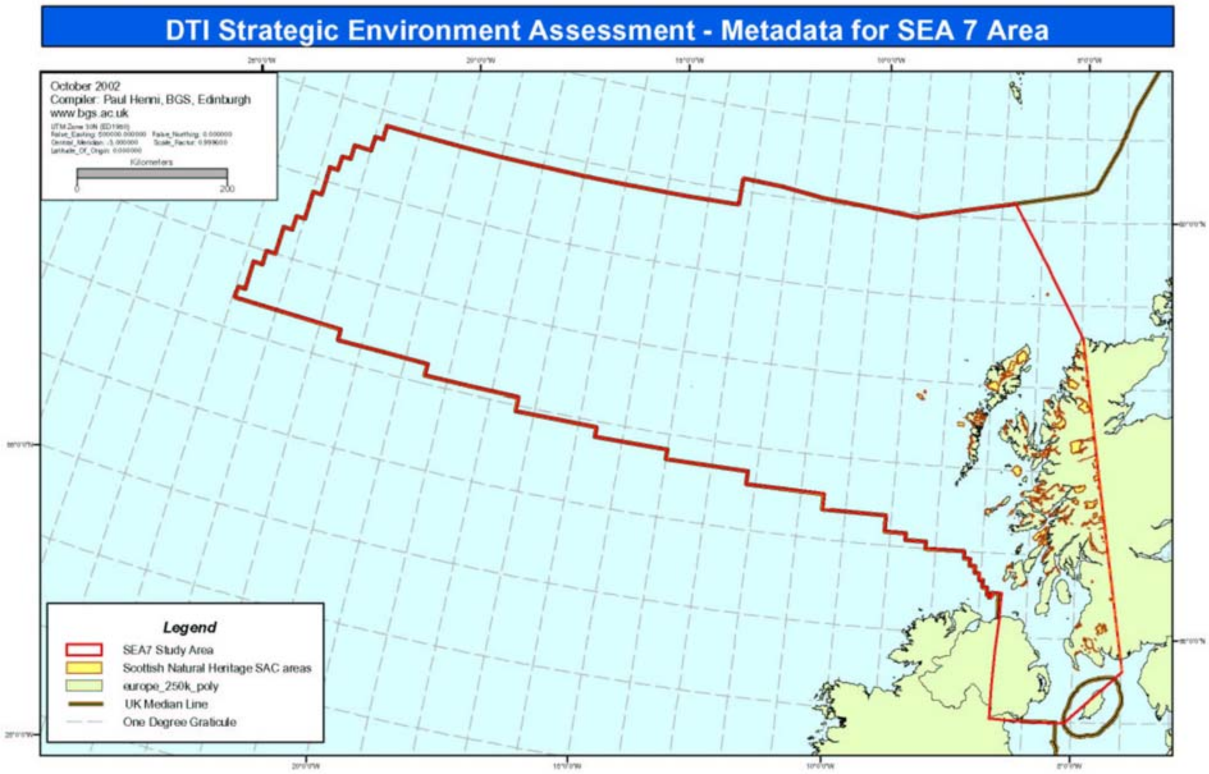

Figure 19. BGS and SOC Van Veen, multicore and spadecore (other core OC)
www.bgs.ac.uk, www.boscor.org, (boscor temporarily out of order October 2002)

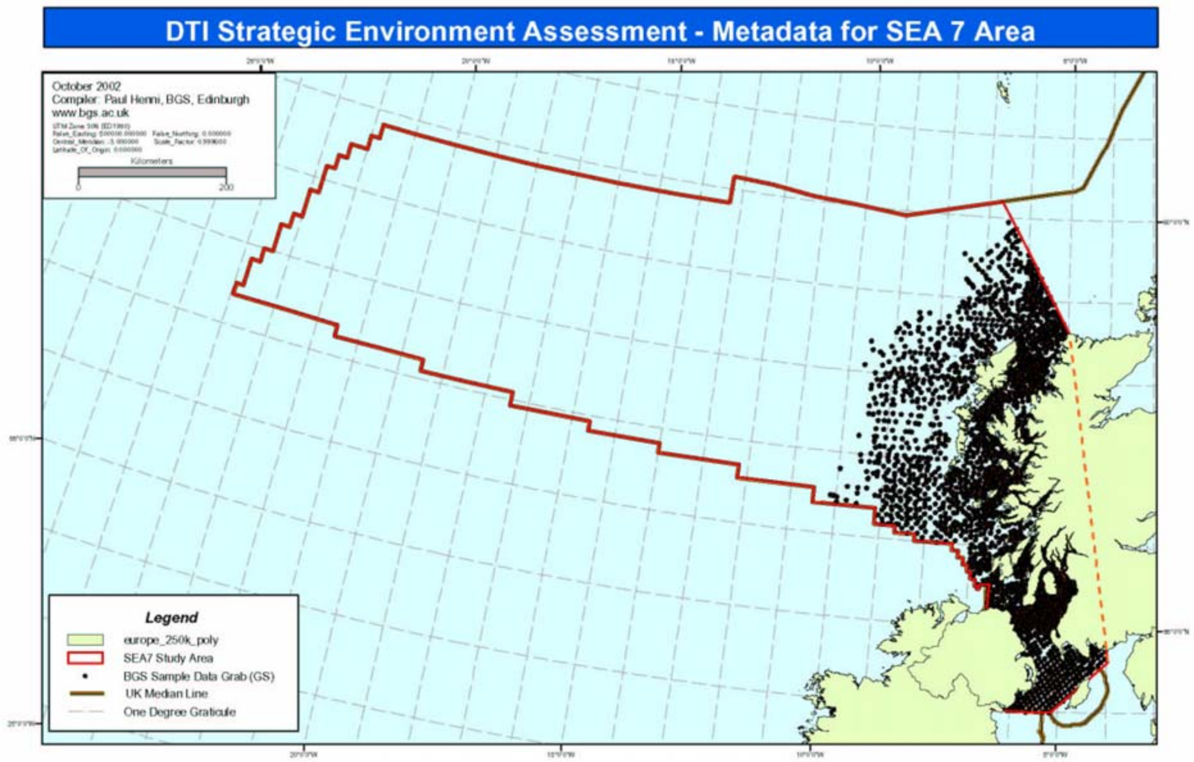

Figure 20. BGS Shipek Grab sites www.bgs.ac.uk

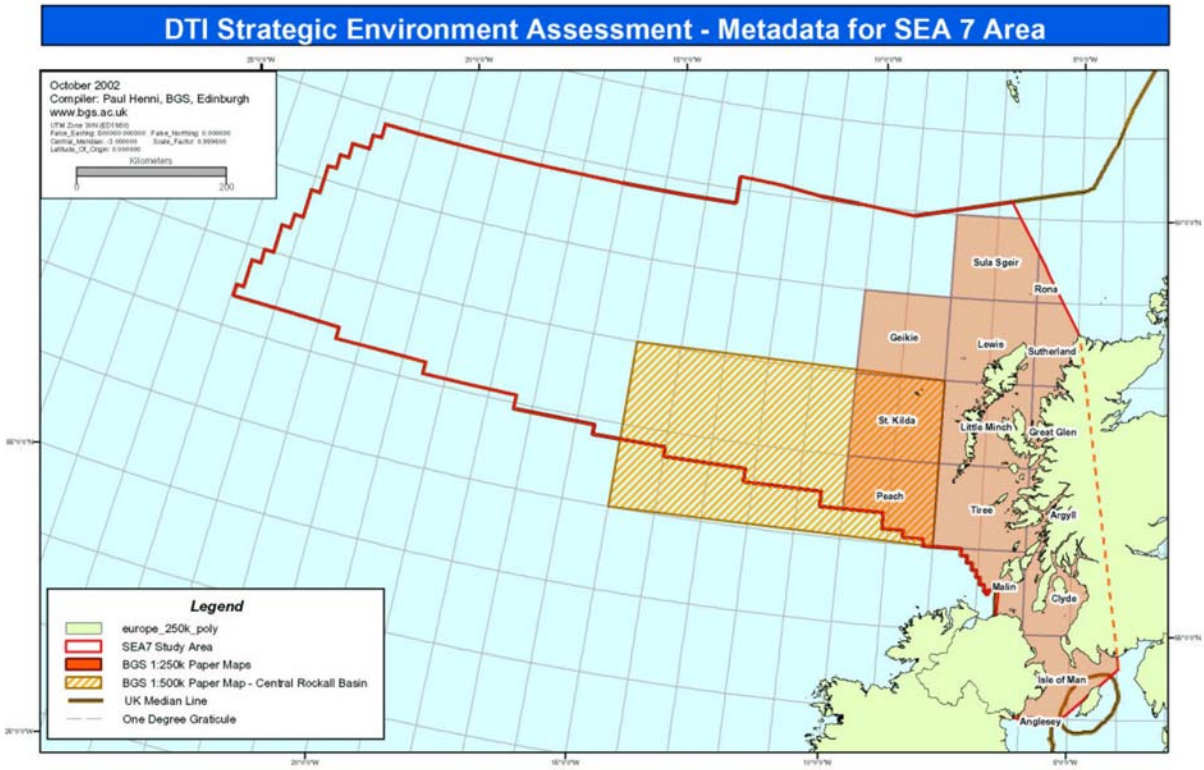

Figure 21. BGS maps solid geology, Quaternary geology, seabed sediment www.bgs.ac.uk

Hard-copy maps 1:250, 000 and 1:500,000 scale of solid geology Rockall Trough

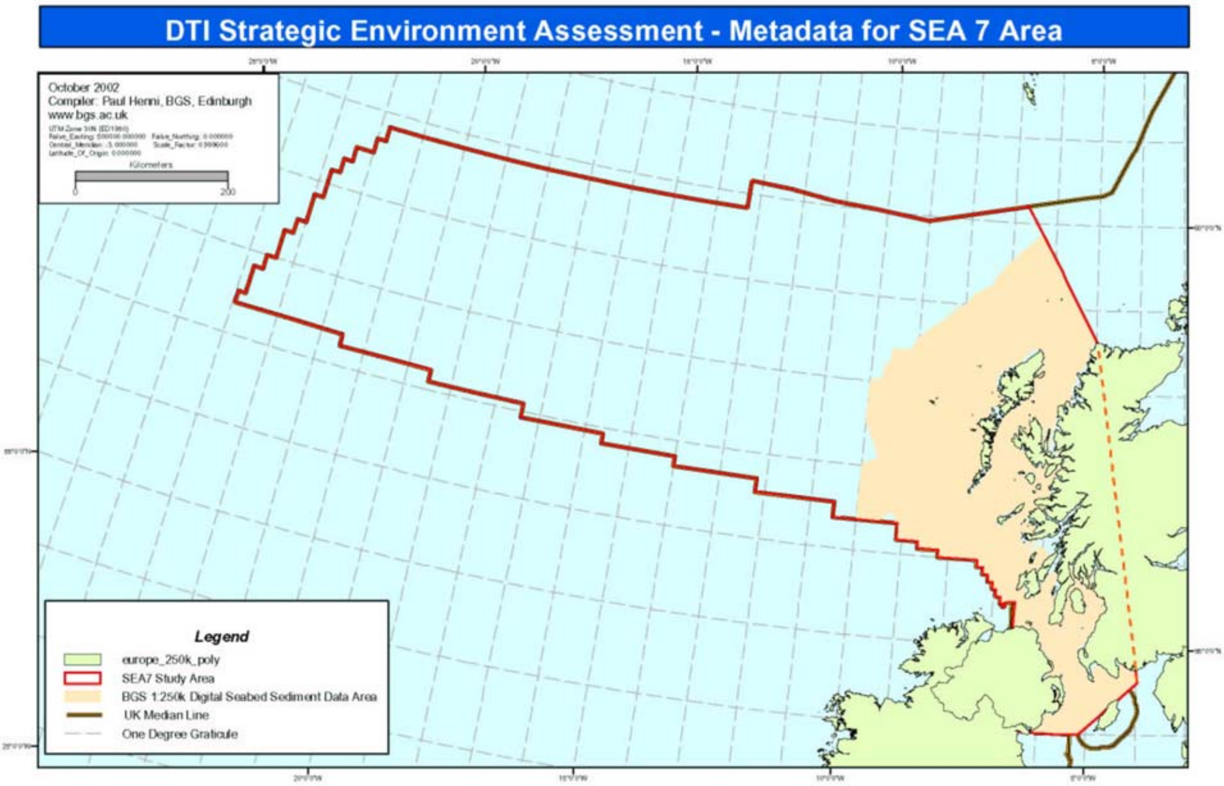

Figure 22. BGS digital regional seabed sediments. www.bgs.ac.uk

Folk classes based on proportions of Wentworth grain size scales.

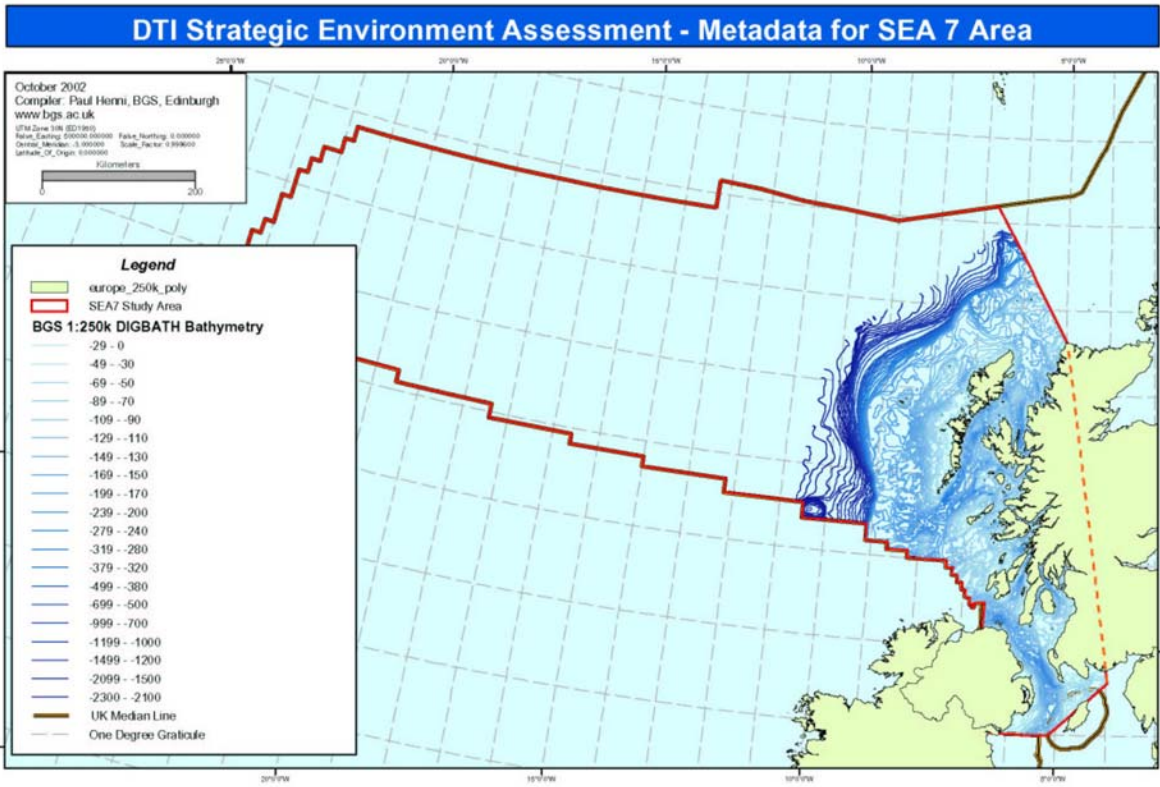

Figure 23. BGS regional digital bathymetric data www.bgs.ac.uk

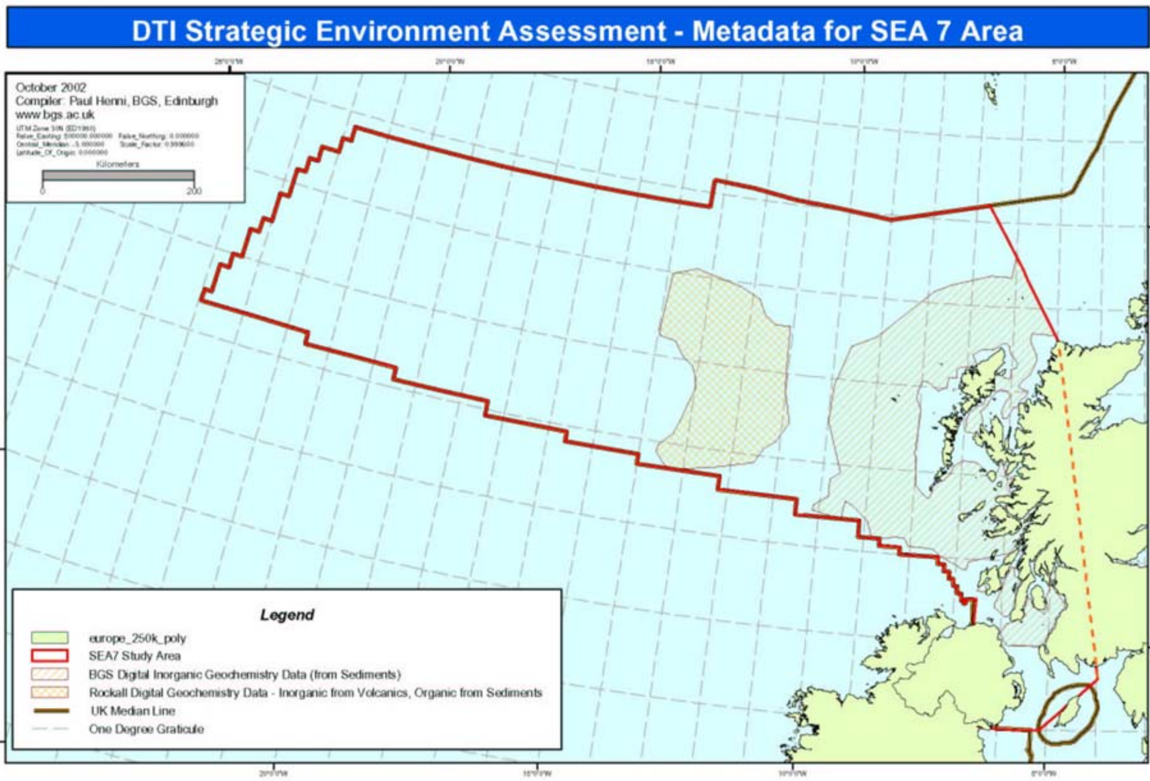

Figure 24. BGS inorganic and organic chemistry www.bgs.ac.uk

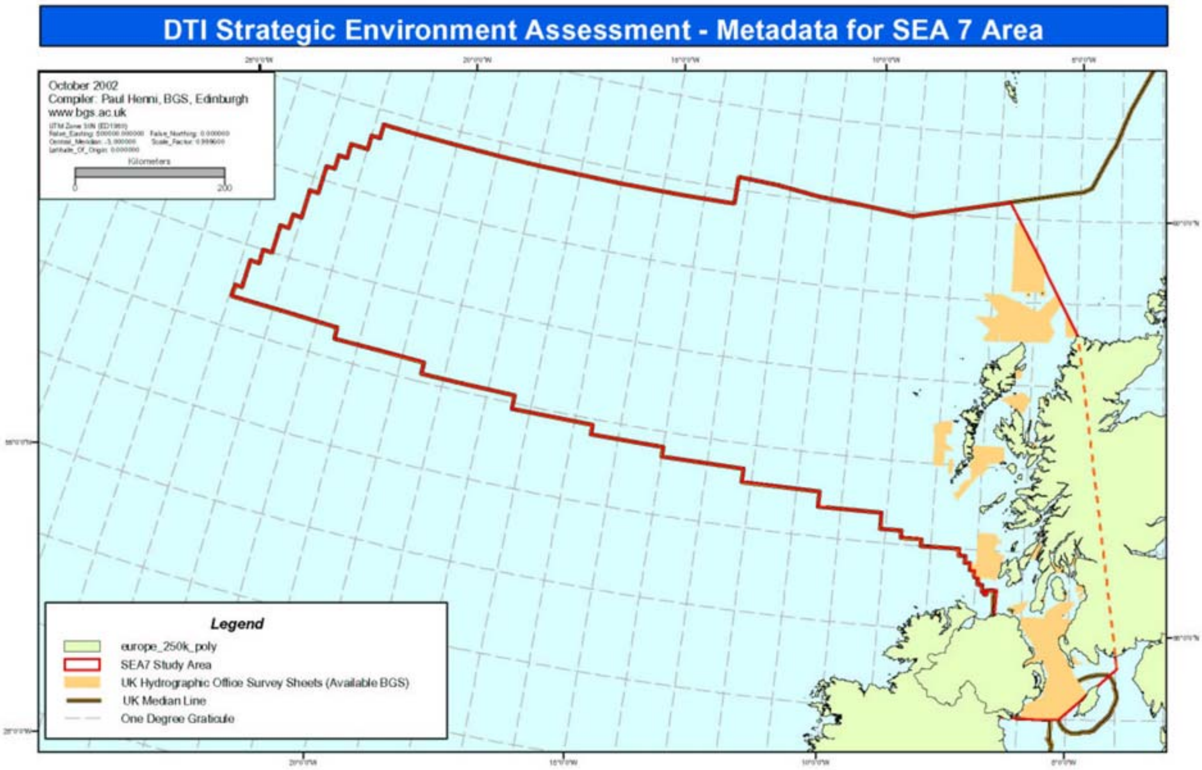

Figure 25. Hydrographic Office bathymetry, sidescan sonar, sediment sample data and interpretation www.bgs.ac.uk

Availability from the BGS varies. BGS holds some data in arrears from the Hydrographic Office which has the up-to-date holdings. Arrangements prior to 1995 meant that much Hydrographic Office data had been incorporated into the BGS seabed sediment maps published at1:250,000 scale. Arrangements after 1995 are that the raw data are subject to licensing agreements.

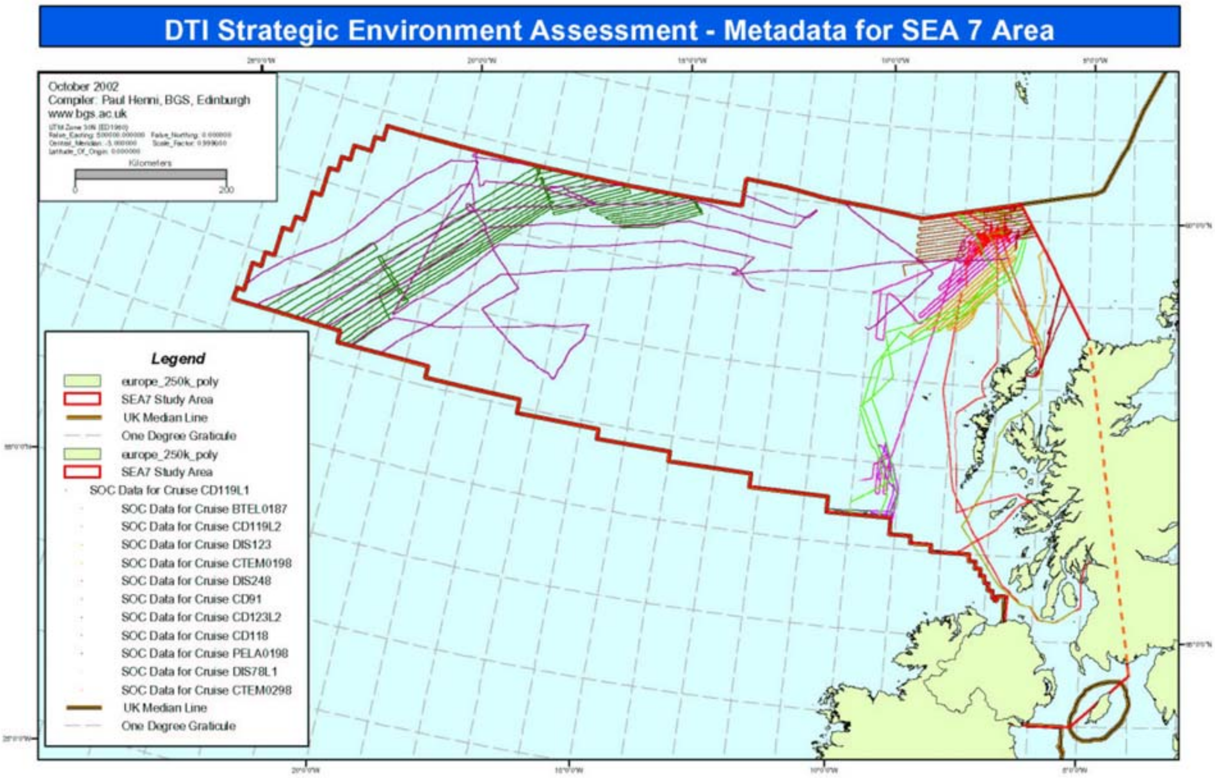

Figure 26. SOC project surveys: mainly Gloria and Tobi sidescan survey
http://www.soc.soton.ac.uk/cgi-bin/seadog/seadog.pl

As for the BGS data summarised above, the data classes within the SOC project surveys can be subdivided. The SOC survey data has been acquired with more emphasis on seabed project-specific regional deep-water sidescan and swath bathymetric surveys, sometimes accompanied by pinger or chirp profiles. Expanded key to Figure 26, see Table 1.

Cruise Name or Number	Data Type(s)	Date	Data Owner
R/V Colonel Templar 0198	30 kHz TOBI Sidescan Imagery, 3.5 kHz profiles, 7.5 kHz profiles	May 98	AFEN
RRS Discovery 123	6.5 kHz GLORIA Sidescan Imagery, 12 kHz echo-sounder profiles	Sep 81	SOC
R/V Pelagia 0198	30 kHz TOBI Sidescan Imagery, 7.5 kHz profiles	Jul 98	IRISH DATA
Kommander Subsea (BTEL0187)	6.5 kHz GLORIA Sidescan Imagery, 12 kHz echo-sounder profiles(?)	Feb-Mar 87	DTI
RRS Charles Darwin 119L1	30 kHz TOBI Sidescan Imagery, 3.5 kHz profiles, 7.5 kHz profiles	Jun 99	DTI
RRS Charles Darwin 119L2	30 kHz TOBI Sidescan Imagery, 3.5 kHz profiles, 7.5 kHz profiles	Aug-Sep 99	DTI
RRS Charles Darwin 123L2	30 kHz TOBI Sidescan Imagery, 3.5 kHz profiles, 7.5 kHz profiles	Jun-Jul 00	DTI
RRS Charles Darwin 91	30 kHz TOBI Sidescan Imagery, 3.5 kHz profiles, 7.5 kHz profiles	Feb-Mar 95	SOC
R/V Colonel Templar 0298	30 kHz TOBI Sidescan Imagery, 3.5 kHz profiles, 7.5 kHz profiles	May-Jun 98	AFEN
RRS Discovery 248	410 kHz Sidescan imagery, 12 kHz echo-sounder	Jul-Aug 98	SOC
RRS Discovery 78L1	12 kHz echo-sounder	Sep 76	SOC
RRS Charles Darwin 118	SIMRAD EM12 multibeam bathymetry and acoustic backscatter	Apr-May 99	DTI (UNCLOS)
Cruises NOT on the SeaDOG database, but potentially accessible through SOC			
R/V Professor Logachev TTR7 Cruise	Various 3.5 kHz, sidescan sonar and bathymetry	Jul-Aug 97	TTR (contact via SOC)
R/V Professor Logachev TTR8 Cruise	Various 3.5 kHz, sidescan sonar and bathymetry, video images	98	TTR (contact via SOC)
R/V Professor Logachev TTR9 Cruise	Various 3.5 kHz, sidescan sonar and bathymetry, cores	Jun-Jul 99	TTR (contact via SOC)
R/V Professor Logachev TTR10 Cruise	Various 3.5 kHz, sidescan sonar and bathymetry, video images, samples	Jul-Aug 00	TTR (contact via SOC)
R/V Professor Logachev TTR12 Cruise	Various 3.5 kHz, sidescan sonar and bathymetry, video images, samples	Jun-Jul 02	TTR (contact via SOC)

Table 1. List of Cruises held on the SOC SeaDOG database with seabed and shallow subseabed data http://www.soc.soton.ac.uk/cgi-bin/seadog/seadog.pl

Seabed habitat surveys have been completed of Special Areas of Conservation (SACs), and maps of these surveys include integration of seabed geology with biotopes. The areas of offshore interest extend from the coast to 12 nautical miles offshore (Figure 27).

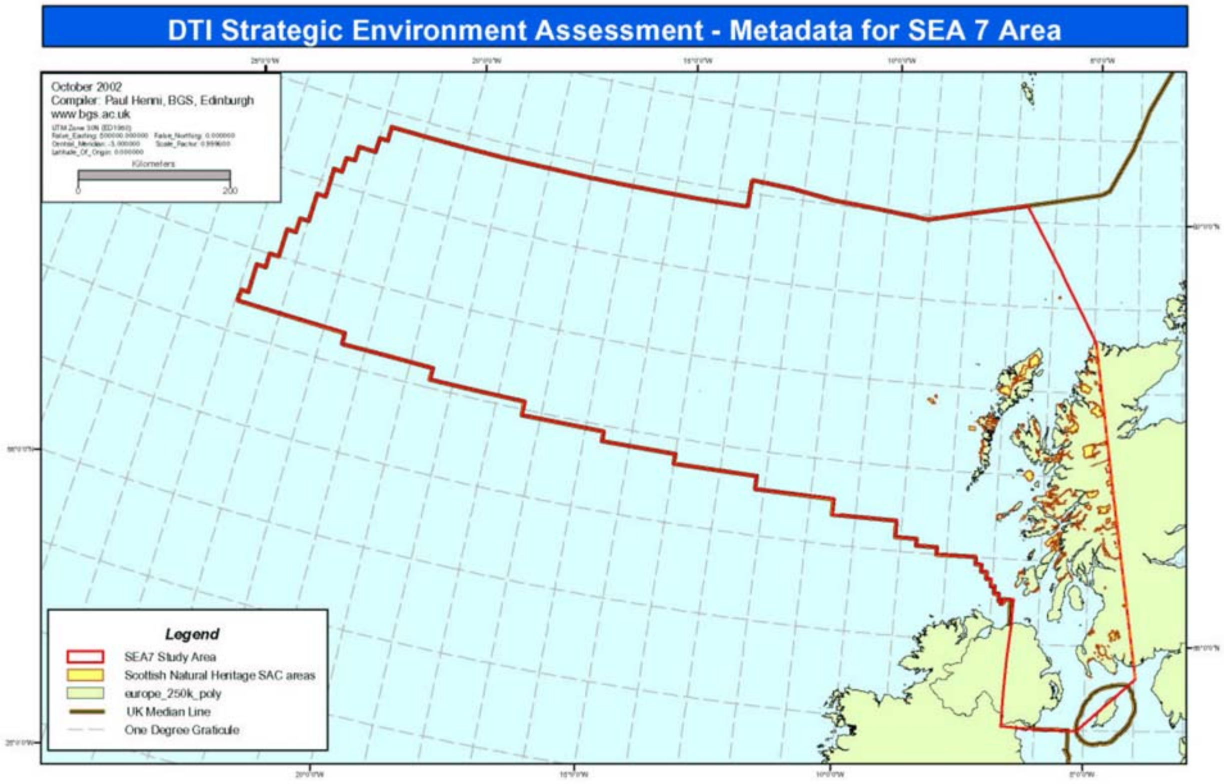

Figure 27. Scottish Natural Heritage Special Areas of Conservation. www.snh.org.uk

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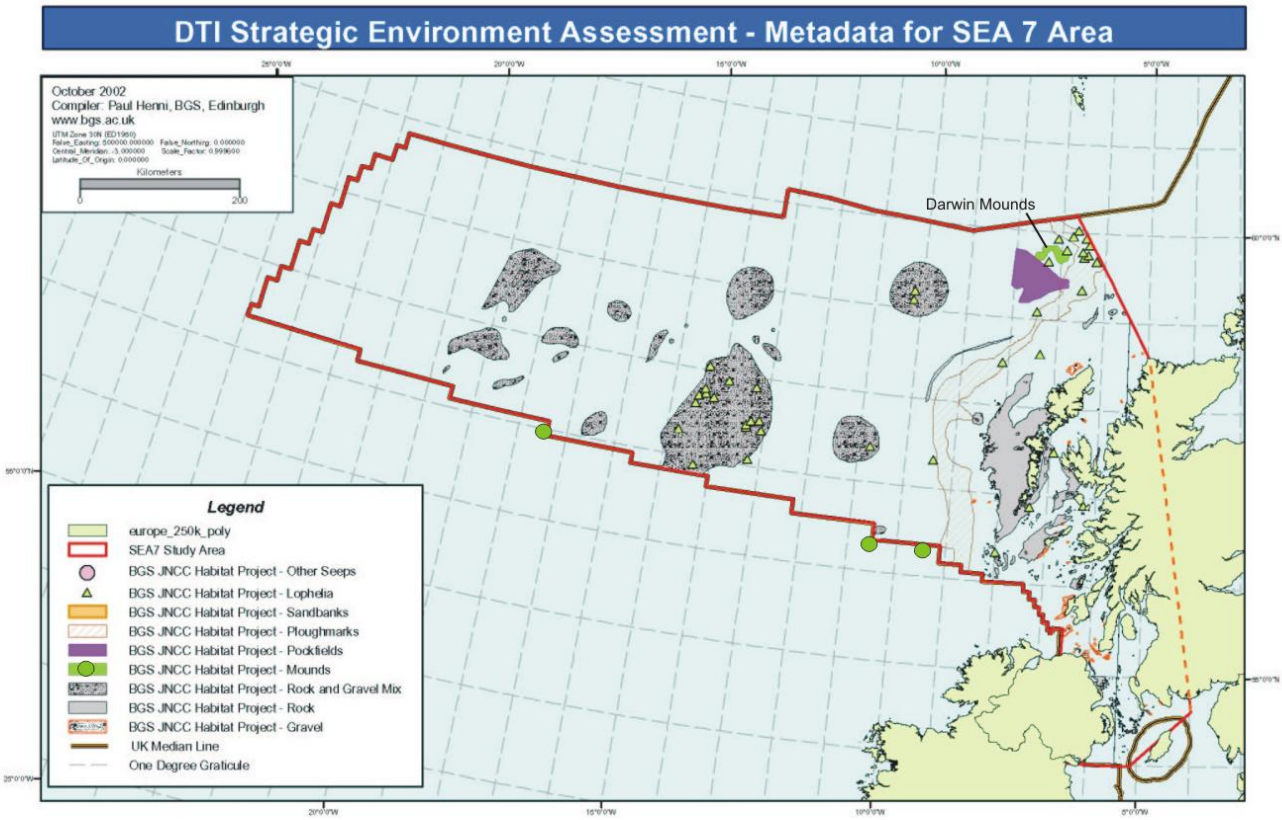

Figure 28. Joint Nature Conservancy Council: Project themes, locations www.jnc.gov.uk.

Regional research programmes, for example for the Joint Nature Conservancy Council (Figure 28), have been completed as desk studies using existing data. Note that some of the mound fields illustrated on Figure 28 extend across the UK-Irish border. These mounds are more numerous and extensive in the Irish sector and are the subject of a special report completed for SEA7 some 9 months later than this report (Unnithan,V. and Shannon, P. 2003. SEA7. Geology. Marine and Petroleum Geology Research Group . Department of Geology, University College, Dublin).

A pilot scheme (not illustrated) was launched October 2002 with a whole ecosystem approach to regional sea management. This is being funded by DEFRA for the Irish Sea and the northern boundary of this scheme extends from the south end on the Mull of Kintyre to Rathlin in Northern Ireland.

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Other websites

PAN EUROPEAN

A huge dataset of European metadata is likely to exist, some of which may be too risky and time consuming (costly) to be of use for environmental assessment. There was not enough money in the project to examine the full potential to see if these other European resources could add significantly to this project.

- GEIXS (Geological Information Exchange System) http://geixs.brgm.fr/
- EU-SEASED www.eu-seased.net. The EU-SEASED website consists of metadata from the following EC 4th and 5th Framework projects
    - EUMARSIN (European Marine Sediment Information Network)
    - EUROSEISMIC (European Marine Seismic Metadata and Information Centre)
    - EUROCORE (A searchable Internet database of seabed samples from the Ocean Basins held at European Institutions)
- SEASEARCH (Gateway to Oceanographic and Marine Data & Information in Europe) www.sea-search.net. Includes:
    - EDMED (European Directory of Marine Environmental Datasets)
- PANGAEA http://www.pangaea.de/

  PANGAEA is a public data library on the Internet aimed at archiving, publishing and distributing geo-coded data with special emphasis on environmental, marine and geological research. It is operated by the Alfred Wegener Institute for Polar and Marine Research and the Centre for Marine Environmental Sciences at the University of Bremen.

- PAN-NATIONAL AGENCY/DEPARTMENT/UNIVERSITY

- NGDF National Geospatial Data Framework (includes 'ask giraffe'), mainly for land based data but extending to the coast www.ngdf.org.uk
- UKMIC UK Marine Information Council www.ukmarine.org
- IACMST . The Inter-Agency Committee on Marine Science and Technology http://www.marine.gov.uk/

  IACMST is a UK Government Committee reporting to the Office of Science and Technology. IACMST is responsible for the Marine Environmental Data Action Group (MEDAG), which, together with the Marine Environmental Data Co-ordinator, forms the UK Marine Environmental Data (UKMED) Network. The network has set up the OceanNET (http://www.oceannet.org/) web site as a portal to data and information about the marine environment. OceanNET also contains a new UK Directory of Coastal Data Sets. UKMED is currently funded by the Defence Science and Technology Laboratory (DSTL), Department for Environment, Food and Rural Affairs (DEFRA), the Environment Agency (EA), Fisheries Research Service (FRS), the Met. Office, the Natural Environment Research Council (NERC) and the UK Hydrographic Office (UKHO).

- Marine equivalent of MAGIC www.magic.gov.uk, has been flagged as a possible way forward for collating UK environmental data with www.cefas.co.uk possibly as a front runner.

- INTRA-RESEARCH COUNCIL/UNIVERSITY

- www.NERC.ac.uk/data/

- INTRA-SURVEY/INSTITUTION

- www.bgs.ac.uk BGS Intranet/Geoscience/Metadata, referred to above for the offshore areas but also covers the coastal boundary
- SOC http://www.soc.soton.ac.uk/cgi-bin/seadog/seadog.pl).

Table 2: Non-BGS/SOC databases with references to cruises/programmes

Database Name	URL
British Oceanographic Data Centre	www.bodc.ac.uk
US National Geophysical Data Centre	www.ngdc.noaa.gov

European Directory of Marine Environmental Data (EDMED)	http://www.bodc.ac.uk/frames/index4.html?../services/edmed/index.html&2

Table 3. List of non BGS/SOC sampling databases.

There are too many samples of many different types and age outside of the BGS and SOC sites referred to above to make a sensible list for this report.

Database Name	URL
US National Geophysical Data Centre	www.ngdc.noaa.gov
1.1 Lamont-Doherty Deep-sea Sample Repository	www.ldeo.columbia.edu/CORE_REPOSITORY/RPH1.html

Table 4. Marine Telephone Cables.

Almost all of the data collected during survey and installation remains as proprietary data and requests for use must be addressed to owners/operators.

Cable Name	European Terminus	Other Terminus	Owner(s)/Operator(s)	Note(s)
TAT-10 Transatlantic 10	Norden, Germany	Rhode Island, U.S.A	AT&T, Deutsche Telekom, Netherlands PTT	In-Service: 1992
AC1	Beverwyjk(Neth)	Brookhaven U.S.A.	Global Crossing	In-Service: May 1998
TAT-14 Transatlantic 14		New Jersey, U.S.A.	AT&T, BT, Sprint	Under Construction: October 2000

Endnote © format

There are more than 690 references saved in digital Endnote © format.

Bibliographic references have all been assumed to be quality rank 3-5 but have not been individually ranked. All published maps have been assigned a ranking of 5.

The notes field contains items a to d relating to the following legend:

a. location of data (where is it archived/stored)
b. cost (free or cost)

c. quality ranks: 1. only to be used in extremis 2. quality uncertain or very patchy or of doubtful cost effectiveness to retrieve 3. fair to mediocre 4. data useable and free of charge or at cost 5. data should be used even if it incurs cost (eg. licensing or processing)

d. latitude and longitude limits for maps

For the output in Endnote © without ranking see Appendix 4.

5. References

See Endnote compilation.

Appendix 1 Geological processes

The SEA7 project area comprises a major part of the coast, the continental shelf, the slopes and the deep-water basins occurring to the west of UK (Figure 2).

The coast and parts of the adjacent continental shelf were connected to the land by regional ice sheets during at least 4 regional glaciations at intervals between 10,000 years and more than approximately 800,000 years ago. The significance of the former regional glaciations to the geomorphology of SEA7 and to the composition of the seabed sediments is that they were associated with thick continental ice sheets that flowed and caused severe sub-ice sheet erosion of the underlying ground. The erosion formed the complex fjord-like shape of the coastline and transferred mainly non-biogenic gravelly and muddy sediments from the Scottish mainland and inner shelf to the seaward margins of the continental ice sheets. They also contributed to modern micro-seismicity and crustal warp originating from the post-glacial adjustments to removal of large volumes of sediment, changes of ice thickness, and sea-level rise. Although the modern SEA7 has very little non-biogenic sediment input it is in a boreal temperate climate zone set in a fertile sea with strong near-bottom currents on the continental shelf and slope. In these environments the modern sediments mainly consist of mixtures of reworked glacial sediments and post-glacial shell carbonates. Thus the remobilised sediments are muddy in locations that are sheltered from near-bottom currents, they are sandy in the more exposed locations and all the sediment size fractions typically contain >10% biogenic carbonate.

The seabed environments are strongly influenced by the geomorphology, sediment texture and sediment composition. In turn these are influenced by the origins and relative abundances of the seabed sediment sources and the amount of sediment reworking by biological processes and by geostrophic, tide, wind and storm-surge generated near-bottom currents.

Coastal geological processes are strongly influenced by the tidal range, which varies from 1- 4m with position on the coast. Coastal and nearshore processes are also strongly influenced by exposure to strong waves. For example, extreme-wave-orbital near-bottom current-strengths of more than 600cm/sec have been estimated for the 50-year storm in water depths of less than 100m at sites west of the Hebrides (eg. Pantin, 2001). Under these conditions seabed lithic gravel (>2mm diameter) is readily mobilised.

Further offshore, mean tidal, wave and geostrophically-generated near-bottom currents range from less than 50cm/sec to more than 200cm/sec, so that the exposed nearshore, continental shelf and upper slope seabed environments in SEA7 are characterised by mobile sands and silts (eg. Pantin, 1991). During the major part of modern times the near bottom currents on the middle to outer Hebrides Shelf at the shelfbreak are directed towards the northeast (e.g. Huthnance, 1986). Here, the current speeds vary on a regional scale with the shelf and slope geometry, that is, with the geological structure that underpins the changes to the seabed geomorphology.

At the mesoscale, the near-bottom currents and shelf and shelfedge seabed properties also vary with changes of seabed topography associated with rock platforms, basins, moraines and submarine fans, most of which have also been more or less shaped by glacigene processes (e.g. Holmes and Stoker, 1990; Stoker *et al*, 1993; Stoker, 1995). At smaller scales, gravel ridges and intervening sand infill are associated with iceberg scour in a zone extending from the mid-shelf and over the shelfedge to approximately 450m water depth on the upper slope. Mobile sediment waves are found in environments ranging from the coast and continental shelf to the deepest-water basins and vary in size from the almost-ubiquitous sand ripples (<60cm wavelength) to the less common very large bedforms (>100m wavelength).

Outside of the areas affected by canyons and submarine landslides, the modern deep-basin sedimentary processes are dominated by erosion and deposition from contour-following currents (contouritic processes) and by deposition from the water column by slow settling and slow lateral advection (hemipelagic processes).

Regional slope angles at the margins of the Rockall Trough typically range from 1-4º and occasionally 7-14º on the upper slope. Relatively abrupt increases of slope angles and slope angles in the order of 2º or more commonly map to sediment-drift (contouritic) bedforms, rock crop at or near seabed in areas with very strong currents and to features formed by canyon and submarine landslide processes, these last occurring more frequently south of approximately 57ºN (Armishaw *et a.l*, 1998). Abrupt local changes in seabed gradients in the NE Rockall Basin are also related to isolated submarine landslides and are linked to evidence for sub-seabed fluid migration and seabed fluid expulsion (Baltzer *et al.*, 1998) in an area also noted for seabed mounds and pockmarks (Masson *et al.*, 2001). Modern submarine landslides occur south of approximately 56.5ºN on the Barra and Donegal Fans. These map to relatively steep slope angles, prograding deposits associated with fan build-out towards deep-water and to proximity to the epicentres of modern seismicity (Holmes, 2002).

The deep-water areas of the western Rockall Trough and further west have been relatively sediment starved compared to those of the eastern Rockall Trough and there are relatively few submarine landslides. The seabed morphology of the unconsolidated sediments is predominantly shaped by along-slope sediment transport and hemipelagic sediment deposition and is characterised by sediment plastering or sediment drape over underlying structures.

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Appendix 3 Geographical Keywords

N.E. Atlantic Ocean
Rockall Trough
Northern Rockall Trough
N E Rockall Basin
Maury Channel
Endymion Spur
Hatton Bank
Hatton-Rockall Basin
Rockall Plateau
Rockall
George Bligh Bank
Bill Bailey Bank
North Feni Ridge
Feni Ridge
Rosemary Bank
Wyville Thomson Ridge
Anton Dohrn Seamount
St Kilda
Hebrides Shelf
Hebridean Shelf
Barra Fan
Donegal Fan
Sula Sgeir Fan
Sula Sgeir
Malin Shelf
North Rona
Butt of Lewis
Outer Hebrides
Inner Hebrides
Scottish Mainland
Lewis
South Harris
Benbecula
North Uist
South Uist
Barra
Barra Head
Malin Sea
North Minch
South Minch
The Little Minch
Sound of Raasay
Inner Sound
Raasay
Rona
Skye
Monach Island
Rhum
Eigg
Muck
Tiree
Coll
Mull
Staffa
Treshnish Islands
Skerrymore
Blackstones Bank
Mull of Kintyre
Rathlin Island
North Channel
Ailsa Craig
Firth of Clyde
Beauforts Dyke
Luce Bay
Isle of Man
Dundalk Bay
Belfast
Belfast Loch
Clyde
Ailsa Craig
Bute
Great Cumbrae
Little Cumbrae
Inner Clyde, Clyde
Enard Bay
Rubha Coiseach
Edrochillin Bay
Cape Wrath
Solan Bank
Glasgow
Stanton Bank(s)
Geikie Bulge
Darwin Mounds
Flannan Trough
Geikie Escarpment
Larne
Kishorn
Ronan Basin
Hatton Drift
Iceland Basin
Peach Slide
Summer Islands
Priest Island
Finnan Islands
Western Island
Shiant Islands
Loch Roag
W. Loch Tarbet
Pabbay
Monach Islands
Sound of Barra
Vatersay Sound

Loch Resort
The Narrows
Loch Maddy
Loch Uskavagh
Loch Carman
Loch Skipport
Loch Eynort
Loch Boisdale
Castle Bay
Loch Vatersay Sound
Red Point
Berneray Sound
Shillay Sound
Stornoway
Loch Grimashadur
Loch Luirbost
Sound of Harris
Village Bay
Loch Bracadale
Ardnamurchan Point
Tiree Passage
Loch Soridain
Jura Sound
Firth of Lorne
Oban
Loch Fyne
Loch Long
Loch Linnhe
Loch Faslane
Greenock
Dumbarton
Sound of Mull
Loch Sunart
Sound of Sleat
Loch Hourne
Loch Alsh
Loch Carron
Loch Torridon
Loch Garloch
Loch Etive
Gruinard Bay
Loch Broom
Loch Kanaird
Loch Inver
Point of Stoer
Eddrachillis Bay
Loch Lauford
Loch Inchard
Kilbrannan Sound
Ailsa Craig
Loch Ryan
Stranraer
Mull of Galloway
Burrow Head
Peel
Isle of Man
Port Erin
Calk Sound
Port St Mary
Castletown Bay
Loch Carlingford
Strangford Loch
Donaghadee Sound
Ardglass Harbour
Killough Harbour
Larne Harbour
The Maidens
Portrush
Kilbrannon Sound
Campbelton Loch
Sanda Island
Holy Loch
Ardrossan
Greenock
Gourock
Gareloch
Rhu Marrows
Faslane
Loch Goil
Loch Striven
Dunoon
Inchmarnock Water
Loch Gilp
Loch Tarbet
Gigha
Sound of Gigha
Corryvrechan
Loch Crinan
Loch Etive
Loch Crenan
Loch Leven
Loch Eil
Ballachulish Bay
Lismore Island
Linn of Morven
Lynn of Lorne
Loch Ailine
L. A’Choire
Loch Nevis
Loch Tudth
Sound of Iona
Treshnish
Gott Bay
Gunna Sound
Loch Eathama
Mallaig
Kyle Rhea
Loch Euich

Loch Alsh

Kyleakin

Strome Narrows

Broadford Bay

Loch Kishorn

Caol Moire

Loch Sheldaig

Ayr Bay

Brodick Bay

Irvine Harbour

Troon Harbour

Ayr Harbour

Ullapool

Firth of Lorne

End of geographical keywords

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Appendix 5

OCCURRENCE OF CARBONATE AND OTHER MOUNDS IN THE SEA7 REGION OF THE ATLANTIC MARGIN

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SUMMARY

In the past decade, a significant amount of new data has been gathered on the geological, ecological and biological aspects of seabed mounds structures in the Atlantic Ocean west of Ireland and the UK. Carbonate mounds are very numerous (>1000), of various sizes and occur as both seabed features and buried mounds. They lie in water depths ranging from 500 to 1500 m and are generally located towards the upper parts of the shelf-slope break along the basin margins, and also on the main basin-bounding banks. Their morphology and shape range from simple cones to complex amalgamated ridge features covering up to 5 km^2 and standing up to 300 m in height. While the internal structures and composition of the carbonate mounds are poorly constrained, their surfaces are generally covered by reef-building cold-water coral species such as *Lophelia pertusa* and *Madrepora oculata*. In addition to carbonate mounds, volcanic cones and possible mud mounds have also been identified in the region.

This report focuses on the distribution, classification and internal (seismic) structure of carbonate mounds to the west of Ireland and the UK within the SEA7 region and its general environs. It also provides an overview of the main results from ongoing research in EU 5th Framework projects such as GEOMOUND, ECOMOUND and ACES. Various models for the origin and growth of carbonate mounds have been proposed in the literature. These range from hydrocarbon seepage and nutrient models to oceanographic and current influences and are discussed. The report also provides a comprehensive bibliography of mound references, a map of mound locations and a compendium of relevant metadata from the region.

Introduction

Extensive clusters of carbonate build-up and mound structures have been identified at the seabed or in the shallow subsurface in the North Atlantic. Their formation is generally linked to the development and growth of deep, cold-water coral species such as *Lophelia pertusa* and *Madrepora oculata*.

Recent discoveries of reefs and mound structures in the North Atlantic, during various research cruises such as the Training Through Research Cruises (TTR 97), Atlantic Irish Rockall Survey (AIRS96), Belgica Cruises 1997 - 1998, and Pelagia ENAM cruises 1996 - 1998, have generated a great deal of interest in the genesis of deep water bioherms. The possible linkage of modern seabed mounds and their fossil counterparts with hydrocarbon seepage and petroleum plays has intensified the study of these features.

Carbonate mud mounds in shallow waters are defined by Bosence and Bridges (1995) as "*a carbonate build-up having a depositional relief and being composed dominantly of carbonate mud, peloidal and or micrite*". Classical mounds, as described by various authors (e.g. Monty 1995, Pratt 1995) are restricted to water depths of 50 - 100 m. The most striking characteristic of the mounded structures in the North Atlantic is the water depths at which they occur i.e. 500 - 1000m. These seabed mounds are also unique as regards to their physical size i.e. 10 – 300 m in height and covering an area of a few 100 m^2 to 3 km^2 in some cases. In addition to carbonate mound, volcanic cones and possible mud volcanoes (mud mounds) have also been identified using high-resolution swath bathymetry data acquired by the Geological Survey of Ireland as part of its recent Seabed Survey, and high resolution magnetic and gravity data acquired by the Irish Petroleum Affairs Division.

This report summarises data from research on deep, cold-water carbonate mounds, drawing on the wealth of information available from the various scientific cruises, research meetings and recent publications. Current models attempting to shed light on the genesis and evolution of these features are highlighted and discussed.

Objectives

The scope of the present report includes:

- A review of current knowledge on the occurrence of carbonate and other mounds features that support unusual biological communities in the general region of interest (SEA7: SW corner 22.3°W, 52.5°N & NE corner 4°W, 61.7°N) (Fig. 1).
- Collation and inventory of known (carbonate) mound localities in the region of interest.
- To provide a bibliography providing relevant sources of information on carbonate mound work.
- To provide an inventory of meta data for the known areas and general environs.

Deliverables

In addition to a paper copy of this report, a CD-ROM accompanies this report, which includes:

1. This report in Word Format
2. Bibliography in Endnote format
3. Inventory of meta-data
4. ArcView 3.2 Project with GEBCO-CE bathymetry with mound locations superimposed.

Historical Background to Carbonate mound research

The scientific expeditions of Wyville-Thomson, Carpenter and Jeffreys in the early 1870s onboard the HMS Porcupine west of Ireland led to the discovery of numerous hitherto unidentified deep-sea fauna. During these cruises dredge samples of deep-sea coral were obtained. The occurrence of the deep-sea, cold water coral species *Lophelia pertusa* was first reported by Thomson (1874). Scientific work continued during the early 1900's in the Porcupine Seabight during which the Helga and Helga II worked on an extensive series of stations, particularly on the eastern and northern flanks of the Seabight, in water depths of less than 1600 m (Le Danois, 1948).

During the First and Second World wars relatively little work was done in the region. The only exception was Le Danois' synoptic account of the continental slope fauna off the coasts of northwestern Europe with remarkable details on the general facies in the Porcupine Seabight. His facies interpretation of different European continental slope types and showed the sites of coral occurrences. According to Le Danois, these occurred mostly in a narrow bathymetric zone between 500-1000 m along the continental slope and formed huge belts up to several hundreds of meters high and thousands of meters long. In the Porcupine Seabight he reported such a band of coral on the eastern flank and named it "massif de la Baie de Dingle".

After Le Danois's work on corals to the west of Ireland and U.K., the focus of deep-sea coral research shifted to the Norwegian margin. Ever since the first detailed description of *Lophelia pertusa* detailed studies on the biology and anatomy of deep-sea corals especially *Lophelia pertusa, Madrepora, Desmophyllum and Dendroophyllia* were subject of many research projects (Freiwald, 1998; Hovland and Mortensen, 1999; Mortensen, 2000). Also in other areas of the European margin, *Lophelia* was studied but less intensively than in Norway. Coral structures have been found along the northwest continental margin in the fjords and offshore Norway (Freiwald, 1998; Hovland and Mortensen, 1999; Mortensen, 2000), around the British Isles (Wilson, 1975; Wilson, 1979a; Wilson, 1979b), the Faroe Islands (Frederiksen et al., 1992; Jensen and Frederiksen, 1992), the Rockall Bank (Scoffin et al., 1980; Wilson, 1979c), the Rockall Trough (de Haas et al., 2000; Kenyon et al., 1998), the Gollum channels (Tudhope and Scoffin, 1995), the Porcupine Bank (Scoffin and Bowes, 1988) and in the Mediterranean Sea (Zibrowius, 1980). In addition to the northeastern Atlantic, corals and coral structures have also been reported along the margin of West Africa (Zibrowius and Gili, 1990), in the northwest Atlantic Blake Plateau (Reed, 1992; Stetson et al., 1962), near the Bahamas (Messing et al., 1990; Mullins et al., 1981; Neumann et al., 1977; Neumann and Paull, 1998), on Hatteras Slope (Paull et al., 2000), in the Gulf of Mexico (Moore and Bullis, 1960) and from a few scattered records from the Pacific (Squires, 1965) and Indian Ocean (Rogers, 1999).

In the early 1990s the deep-water coral structures to the west of Ireland and U.K. were the focus of academic and commercial hydrocarbon interest. An extensive seismic and sampling surveys for oil exploration in the Porcupine Seabight showed mounded dome-like structures on the seabed. Gravity cores from the mounds yielded *Lophelia pertusa* and mostly muddy sediments. The publication by Hovland et al. (1994) suggested a relationship between mounds and interpreted deeper faults underneath the mounds and proposed a model linking hydrocarbon seepage and mound occurrence.

These observations and the proposed model resulted in renewed academic interest in the subsurface of the Porcupine Seabight. The first cruise to the mounds in the Porcupine Seabight was organized by the RCMG (Renard Centre of Marine Geology) in the framework of the EU MAST III projects - CORSAIRES and ENAM II to study slope instabilities along the eastern flank of the Porcupine Seabight with high-resolution seismic profiles. This first cruise by the RV Belgica found in addition to the surface mounds reported by Hovland et al. (1994) discovered numerous buried mound features further to the north of the Hovland province. This first successful seismic survey was followed by a Training Through Research- CORSAIRES cruise (Kenyon et al., 1998) during which shallow sediment cores and sidescan sonar data was collected from different mound provinces. During the summer of 1998 in the course of a large-scale regional survey of the seabed by the Atlantic Frontier Environmental Network (AFEN) mounds now called the Darwin mounds were discovered. The findings of these cruises led to the funding of three EU funded projects - GEOMOUND, ECOMOUND and ACES - with the aim of studying the internal and external controls on coral mound build-ups and the biology of the deep-water corals along the NE European margins. The Geological Survey of Ireland has recently completed an extensive swath bathymetry survey across the Irish designated waters west of Ireland and has detected many new mounds.

Carbonate Mounds

Carbonate mounds in the North Atlantic have been identified from their surface and subsurface (seismic) morphology. The carbonate mound catalogue presented in this report has been compiled by the authors from a variety of data sources: the updated seismic catalogue by Croker & Oloughlin (1998), De Mol (2002), Unnithan (2001), GSI Seabed Survey (pers. comm.) and published sources. The datasets used to identify the mound features include sidescan sonar (TOBI, GLORIA, OKEAN, ORETECH), seismic (both commercial and academic), multibeam (GSI Seabed Survey) and ROV video (Victor6000).

1.3 MOUND TYPES

The carbonate mounds can be broadly categorised into surface and buried structures. A carpet of coral debris, which supports a living coral fauna consisting mainly of *Lophelia pertusa* and *Madrepora Oculata*, covers the surface mounds (Fig. 5). In addition to these colonial species, the solitary coral *Desmophyllum cristagalli* and the octocoral *Stylaster* are also occasionally present. On the basis of ROV, multibeam, sidescan sonar, echosounder and seismic records, a number of mound provinces have been identified. They occur in the northern and eastern Porcupine Seabight, Porcupine, Rockall, Hatton and Fangorn banks, to the west of Ireland (see Figs 1 & 2). The published literature makes reference to a large number of mound provinces with a proliferation of names. The names are based on a variety of characteristics including geographic location, morphology, internal geometry and even the names of either the vessels or scientists involved in their original discovery. Mounds can be either surface or buried features. They are principally located along the banks and shelf-slope breaks (Fig. 2). In addition, many samples or corals have been recovered or reported from dredge samples along the Atlantic margin west of Ireland and the UK (Fig. 3). The main mound provinces include the following:

1.3.1 Hovland Mound Province

This is named after Martin Hovland, lead author of a pioneering paper on mounds in the northern Porcupine Seabight (Hovland et al., 1994) (Fig. 4). These mounds are generally conical to dome shaped structures 1.5 km in diameter and about 150 m in height (Fig. 6). They are situated around the 700 to 800 m isobaths. These mounds are each typically surrounded by a distinct moat (up to 50 m deep). Seismic characteristics include pull-up of parallel reflectors just below the mounds. Characteristic mounds include the Propellor and Perseverance mounds.

1.3.2 Belgica Mound Province

This is named after the ship that discovered these features along the eastern margin of the Porcupine Seabight during a scientific cruise in the summer of 1997. These structures are pinnacle or conical mounds with similar dimensions as the Hovland mounds (Fig. 7). They are found in groups forming echelon NNE-SSW trending barriers or banks. The presence of a seismically transparent layer beneath the mounds distinguishes them from the Hovland mounds. Within this province, proto-mound structures (Moira mounds) have been identified on the basis of sonar and ROV observations. These structures are 5-10m high, have a diameter of 20-30m and seem to be morphologically similar to the Darwin mounds identified in the northern U.K. Rockall Trough (Masson *et al.* 2001). Mounds and mound family sites where detailed work has concentrated during the GEOMOUND and ECOMOUND projects include the Thérèsa Mound and the Challenger Mound.

1.3.3 Pelagia Mound Province

This consists of a cluster of mounds on the northern Porcupine Bank investigated by the RV Pelagia, a Dutch research vessel. These mounds are larger (average 300 m in height, covering a few square km) than the Hovland and Belgica mounds. They are also found in slightly deeper waters (750 to 1200 m). These mounds have complex shapes ranging from conical to elongate (both alongslope and downslope) banks to amalgamated structures (Fig. 8).

1.3.4 Logachev Mound Province

This consists of complex mound structures on the eastern margin of the Rockall Bank, investigated first by the Russian research vessel Professor Logachev in 1997 (Kenyon *et al.* 1998). These mounds, later investigated by the Victor ROV (R2 Site) and TOBI sidescan sonar, show highly complex amalgamated ridge and mound structures (Fig. 9). Seismic profiles across this highlight the downslope trending complex ridge structures. The Rockall Bank mounds, occupying a 100km zone parallel to the bathymetric contours on the Rockall Bank, are smaller and morphologically complex in shape. With respect to the mounds described in previous sections, they are found in shallower waters ranging from 500 - 1000m. The mounds, which are covered by dead and living assemblages of *L. Pertusa* and *M. Oculata*, are perched on what is presumed outcrops of rock, erratics or glacial debris. Sonar and seismic data acquired on the second leg of the TTR 7 cruise, clearly demonstrated this preference for a pre-existing platform to develop on. Seismically, they look similar to the other types of mounds, with a chaotic internal structure and a dominant, high amplitude basal reflector. Along the margins of some of the mounds, there is evidence for velocity pull-up. Strong currents and especially the movement of sand influence the intricate shapes of these mounds. Bedforms due to currents on the SE Rockall Bank show evidence for strong alongslope currents with significant accumulation of coarse sandy material between the mounds being transported and deposited by strong currents. In some cases, there is evidence of sand waves covering the mounds or sand transport across the tops of the mounds. Preliminary results suggests that both the Porcupine Bank and Rockall Bank mounds are covered by a carpet of coral debris which supports a living coral fauna consisting mainly of *L. pertusa* and *M. oculata*. In addition to these colonial species, the solitary coral

Desmophyllum cristagalli and the octocoral *Stylaster* are also occasionally present. Morphologically these mounds appear more complex than the mounds in the Porcupine.

1.3.5 GSI Mound Province

The occurrence of new surface mounds on the Rockall, Hatton and Fangorn banks has been reported by the Geological Survey of Ireland (Geoghegan & Monteys, 2003). These mounds were imaged using multibeam and echosounder data from the Seabed Survey (Fig. 10). Detailed analysis of the extent, size and morphology of these mound structures is ongoing (Geoghegan & Monteys, 2003). Preliminary examination of the Fangorn Bank mounds suggests that they are morphologically similar to the Hovland mounds. The Fangorn Bank mounds have distinct moat structures around the mounds, are generally conical in shape, and are about 350m in height. However, these mounds are found in slightly deeper water (around 1250 m) than the Hovland mounds.

1.3.6 Porcupine Bank Canyon Mound Province

This loosely refers to the mounds found in association with Porcupine Bank Canyon on the southern margin of the Porcupine Ridge. These mounds have been identified on the basis of GLORIA sidescan sonar, echosounder and recently acquired multibeam data (Xavier Monteys pers. comm.). These mounds are conical-shaped structures about 300 m in height and are more frequent on the southern steeper flank of the Porcupine Bank Canyon.

1.3.7 Magellan Mounds

These are numerous (>1000) buried mound-like structures in the northern Porcupine Seabight. The buried mounds or Magellan mounds (Fig. 11), were first observed in 1993 on industrial high resolution seismics and later investigated by Belgica 1997 Cruise in the northern Porcupine Seabight. All the identified Magellan mounds are situated to the north of the Hovland mounds. These mounds have not been found elsewhere in the northern Atlantic and are unique to the Porcupine Seabight. They have no morphological expression at the seafloor and were first identified on the basis of high-resolution seismic data collected by the survey vessel Svitzer Magellan. They are characterised by lung-shaped, ovoid seismically transparent structures, 50 - 100 m in height and up to 250 m in diameter. These mounds are generally found to the north and west of the Hovland Mound Province, in water depths of 500 - 750m. Some of the mounds occur in pairs. Orthogonal seismic lines across some of the mound pairs, shows that these mounds are singular ring shaped mounds around a central kernel. The frequency and size of the Magellan mounds decreases to the north, essentially following the same trend as the Hovland mounds. On seismic sections, the base of the mounds appears to originate from a local unconformable seismic horizon. Surprisingly, there is little or no loss of signal directly below the mounds and all seismic horizons can be traced as continuous horizons. Along the margins of the mounds there is little velocity pull-up and little or no distortion of the seismic horizons. Within the mounds, there is a complete masking or blanketing. No internal structures are observed with the mounds. The seismic horizons directly above the mounds are slightly convex or domed.

1.3.8 Darwin Mounds

These were discovered in the 1998 by scientists from the SOC during the AFEN environmental TOBI survey north and west of Scotland. These mounds are named after the NERC ship RV Charles Darwin. The second group of Darwin mounds were discovered during a DTI survey in 1999. The two fields of mounds cover an area of 13km x 4km and 13km x 9km respectively and are found in water depths ranging from 900 to 1060m. The two surveys discovered in excess of 225 mound structures. Each mound is c. 50-100m in diameter and up to 5m high (Fig. 12). The mounds are found north of a large area of pockmarks and appear to be closely related to these fluid escape features (Masson et al., 2003). The Darwin mounds have a characteristic teardrop shaped 'tails' of moderately high backscatter on TOBI sidescan sonar images spanning a few hundred meters in length downstream (NE-SW) from the mounds. The tops of the mounds are covered by *Lophelia pertusa* and less abundant *Madrepora oculata* and associated fauna. Average density of coral heads is reported to be 1 colony per $4m^2$ (Bett, 2001). The mound tails are characterised by high-density populations of xenophyophores, which are giant protozoans unique to the deep-sea. The pockmark fauna is similar to the background sediments with higher density of large burrows and echinothurid urchins dominate the megafauna.

1.3.9 Other mound structures

On the AIRS GLORIA sonar images, numerous oval features were observed along the lower slope of the northern Porcupine Bank at 54°N and 14°W are (Unnithan, 2001; Kenyon et al., 1998). These are 500m to 1km in diameter and are characterised by very high backscatter. The conical shape is determined from the shape of the shadows, i.e. a conical object has high backscatter on the side facing the transducers and prolonged distinct shadows. While the mounded features bear some resemblances to carbonate mounds, these sharp conical features are interpreted to represent extrusive volcanic cones (Fig. 13). Unfortunately there are no 3.5 kHz echosounder data over these features, but high local magnetic and gravity anomalies support the presence of a volcanic body. Kenyon et al. (1998) describe these conical features using medium range sonar and shallow seismic data. The conical shape and low acoustic penetration of these features (see Fig. 23 of Kenyon et al. 1998) is consistent with volcanic bodies. Grab samples from the features recovered black rocks and manganese encrustations. Kenyon et al. (1998) suggested that the black rocks were igneous/volcanic and their presence may be related to the source of the manganese. Based on seismic and magnetic data Naylor et al. (1999) named these preserved Paleocene volcanic cones as the Droll Igneous Centre. The possibility that some of the igneous cones contain a covering veneer of carbonate coral material cannot be discounted.

There are three oval, 2-10 km in diameter high backscattering areas along the eastern margin of Lorien Bank, south-western Rockall Trough. The boundaries of these regions are well-defined. The surrounding region is characterised by low, homogeneous backscattering. The strong contrast of the oval bodies with the surrounding area suggests an abrupt change in surface texture and hence, lithology. The results from recent swath bathymetry surveys (confidential data PAD) suggest the presence of numerous volcanic seamounts of similar morphology to the Anton Dohrn, but smaller in size, in the vicinity of Lorien Bank (Peter Croker, pers. comm.). Their location, size, shape and backscattering characteristics suggest that these structures are volcanic seamount-type features (Unnithan, 2001). The backscattering characteristics are also similar to those of carbonate mounds. However, individual carbonate mounds are generally an order of magnitude smaller than these features. The recent GSI Seabed survey has brought to light new mound structures of presumed volcanic nature based on their seamount morphology, high magnetic signature. These mounds are found in the southern Rockall Trough, Fangorn Bank and Eriador Seamount (see Fig. 2). In addition, some geophysical evidence has been obtained to suggest the presence of some active mud volcanoes or mud mounds in the Porcupine Seabight (Jean-Pierre Henriet, pers. comm.).

Mound Ages

There is significant debate in academic circles regarding the ages of carbonate mound structures along the margins of the Rockall Trough and Porcupine Seabight. To date, none of the large mounds in the Irish and UK waters has been drilled to the base. Surface box and giant piston cores obtained from the summit and flanks of the mounds provide ages in the order of 200,000 years B.P.

(Andre Freiwald, pers. comm.). Regional seismo-stratigraphic analysis suggests that the base of the mounds in the Porcupine Seabight and Rockall Trough overlies the C10 reflector. This reflector has been dated by the ODP 980/981 drill site in the Rockall Trough as early Pliocene (STRATAGEM Project Report – Atlas, Pat Shannon, pers. comm.). These ages are in general agreement with ages calculated by O'Reilly et al. (2003) based on *Lophelia pertusa* growth rates reported in literature and mound dimensions (height and width) of mounds in the Pelagia province. Seismo-stratigraphic correlation by the RCMG group in Gent (e.g. de Mol, 2001) have proposed a slightly younger Late Pleistocene age based on sample dates from the flanks of the mounds in the eastern Porcupine Seabight.

Faunal Assemblages

There is large faunal variability (nature, distribution and type) between the mounds observed on video footage obtained during the CARACOLE 2001 and Polarstern Victor XIX3a 2003 cruise to the Porcupine Seabight and Rockall Trough mounds. The main species of corals found on all the mounds is *Lopelia pertusa*. Varying amounts of *Madrepora oculata*, *Stylasterid* and *Desmophyllum* are found on the mounds. Mounds such as Perseverance, Propellor and Theresa (see attached meta-dataset Figure CARACOLE for locations) do not have substantial living coral cover and are characterised by a variety of otrehspecies of actinian, antipatharian, gorgonians (soft corals), glass sponges, encrusting (as yet undetermined) yellow and blue sponges, cidaris (sea urchins), arthropods such as *paromola*, *bathynectes* and fish species such as *Lopheus*, *Neocytus helgae*, *Pisces blanoides*, *chimera*. Mounds on the eastern margin of the Rockall Bank are covered by a thick (1-3m) cover of both living and dead *Lophelia pertusa* with *Madrepora oculata*. *Desmophyllum* is not seen on these mounds. Small stylasters are observed growing on these mounds. Characteristics fauna includes stalkless crinoids, large red gorgonians, antipatharians, cup-shaped sponges and a large variety of crab and fishes.

Current Carbonate Mound Models

Models for carbonate mound growth must address aspects of mound initiation, growth and sustenance. In terms of mound initiation, two main end-member models exist in the published literature: 1) hydrocarbon or fluid seepage migration (e.g. Hovland et al., 1994) and 2) sedimentological and oceanographic conditioning (e.g. de Mol, 2002). These models are described and discussed below.

1.4 HYDROCARBON AND FLUID SEEPAGE MODELS

Three models have been proposed an evolution and triggering of the Hovland and the Magellan mounds by hydrocarbon and fluid seepage processes:

• The first model was proposed by Hovland (1990), Hovland et al. (1994, 1998). This suggested a causal relationship between hydrocarbon seeps and deep-water coral features. Deep-water coral banks could form as a consequence of local fertilization that resulted from focused hydrocarbon seepage. In the case of the Hovland mounds in the Porcupine Basin, Hovland et al. (1994) proposed that the coral mound structures are located immediately above major faults, which could function as hydrocarbon migration pathways (Fig. 14). Hydrocarbon seeps provided a food source for bacteria, fertilizing the waters around the seep sites. The model suggested that focused hydrocarbon seeps along the faults or fractures led to local eutrophication and enhanced chemosynthetic bacterial growth, which encouraged and supported higher organisms by providing them with nutrients and a suitable substrate on which to attach. This symbiotic relationship would have laid the basis for further growth of the mounds. The validity of this model has been questioned recently by Bailey et al. (2003), whose analysis of the high-resolution 3-D seismic data from the same area suggests that faults and mounds are not spatially related and that many of the features interpreted as faults by Hovland et al. (1994) are seismic artifacts.

- The potential role of methane in triggering mound growth in the Magellan province has been evoked by Henriet et al. (1998; 2001) in a model developed to explain possible causal relationships between methane migration, slope destabilization and mound growth (Fig. 15). Implicit in this model is a possible phase of hydrate build-up and decay resulting from variations in bottom water temperatures during the last glacial and interglacial periods. This model provides a process for focused seeps around which the coral bank develop, hence forming ring-shaped coral banks in the Magellan province. During Quaternary times, with repeated fluctuations from polar (in front of an Irish ice-sheet) to temperate conditions, extreme variations in bottom water temperatures (up to 11°C) may have translated into cycles of local growth and decay of gas hydrates, fuelled by methane from deeper hydrocarbon reservoirs. The authors suggest that the Magellan mound province coincides with an underlying slope failure, where hydrates may have played a role.

- A third model was proposed by McDonnell (2001) based on the coincidence between coral banks and the relation of underlying Oligocene and Miocene contourite deposits. The underlying contourites may have played a role as fluid migration pathway from underlying Tertiary deltaic strata. However, no direct evidence of migration or of hydrocarbon accumulation are reported in the work of Mc Donnell (2001). Seepage of thermogenic hydrocarbons at the seafloor does occur at the present in the northern part of the Porcupine Basin, in the non-commercial Connemara oil field about 65km north of the Magellan mound province. These seeps appear clearly on industrial seismic data and high resolution seismic sections as high-amplitude patches along reflections, vertical disruption of seismic reflections or vertical zones of chaotic facies, interpreted as gas chimneys (Games, 2001). However, no mounds are reported in this region, while in the Magellan, Hovland or Belgica mound provinces there are no such fluid migration features. Most large faults do not extent to the seafloor and there are no clear indications so far for vertical fluid migration pathways neither on industrial seismic data (McDonnell, 2001) nor on the interpreted high-resolution seismic data. Pockmarks in the region of the coral banks are not active structures but might have been active in the recent past. To date no paleo-pockmarks horizons have been observed in the data set, which can link the mound development to the coral mound evolution.

1.5 SEDIMENTARY AND OCEANOGRAPHIC CONDITIONING MODEL

There is ample evidence from sidescan sonar and echosounder data to suggest that the mounds of the Porcupine and Rockall banks are strongly influenced by currents (O'Reilly et al., 2003). The mounds are generally located in areas (Wilson, 1979) with rugged seabed topography or close to the shelf edge. The corals may have settled in these areas to take advantage of the increased currents and possible suspended matter. Along the Porcupine Bank, there is evidence for a relationship between the occurrence of corals and water stratification. Ahermaphytic corals accumulate below the thermocline which exists at 600-1400m in the Rockall Trough (Rice, 1991).

Changes in currents, water temperature or nutrient supply force the coral colonies to selectively occupy favourable parts of the larger mounds. The dead coral traps pelagic and hemipelagic detritus and when the environmental conditions are favourable for colonisation eventually forms a substrate for the further growth of corals. This model could explain the growth of carbonate mounds as a biological response to changes in environmental conditions coupled with normal pelagic/hemipelagic sedimentation.

The sedimentary and oceanographic model consists of initiation and development phases (e.g. Unnithan et al., 2003):

- Mound initiation: *Lophelia pertusa* needs a hard substrate for initial settlement. For the initiation of mounds, this could be an erosion surface such as the C10, glacial drop-stones or pre-existing topography. In addition to settlement substrate, the presence of a suitable current regime to deliver food and prevent clogging through sedimentation as well as optimum water temperature and salinity regimes govern the distribution of *Lophelia pertusa*. Once successfully established and mound growth initiated, the growth phase of the mound would be influenced by changing oceanographic conditions which dictate the selective survival of certain coral patches.

- Mound development: This starts with the growth and death of coral thickets, cementation and hard-ground formation followed by erosion which provides hard substrate for the next growth cycle at that location (see Fig. 16). Once the mounds are able to generate their own (micro) topography, growth can sustained simply because the corals are in a elevated position with enhanced capacity to catch nutrients and are removed from moving sand. Unnithan et al.'s (2003) observation show that lateral growth of mounds occurs when upper and mid-slope terraces are formed by current action and colonised by corals. Dense coral stands or fronds (often with thin fan-like growth composed of basal dead coral with an outer edge of living coral) show preferential growth on the up current vertical face of the terrace. The dead coral matrix may serve to baffle sediments behind the leading living coral edge promoting extension of the terrace over time following cementation.

1.6 DISCUSSION

In the light of new evidence from various cruises in the northern Porcupine, the Hovland model needs to be modified. Recent sediment and core samples from the mounds show no clear evidence of chemosynthetic faunal assemblages. Furthermore, geochemical and isotope analysis reveals the dominance of a marine 13C fingerprint. Moreover, high-resolution seismic profiles show little evidence for faulting directly beneath the mounds. This implies that a direct hydrocarbon fuelled cycle for the growth of the Hovland mounds is unlikely. However sidescan sonar data from the TTR 7 and recently the Pelagia TOBI 2002 cruises imaged pockmarks in the northern and eastern Porcupine, which suggests that fluid expulsion has occurred in the basin.

A vital component in the seepage models is the causal relation between the distribution of the coral banks and structures identified as potential fluid seepage sites. Henriet et al. (2001) related the buried Magellan mounds to the occurrence of the polygonal faults observed in a Neogene slide succession; Hovland et al. (1994) related the coral banks to deeper faults and McDonnell (2001) to Oligocene contourite deposits in the Magellan and Hovland mounds. All three models assume that for the start-up phase the coral banks are preferentially located at sites where fluid seepage is highest.

Fluids need not necessarily have been hydrocarbons. Basinal brine venting, along unconformities, fractures or by diffusion, could have facilitated the formation of authigenic carbonate, forming hard grounds on which ambient benthic fauna could have settled on (Henriet et al., 1998, 2001; Hovland et al., 1994). The formation of local hard grounds by venting may explain the spatial distribution of the coral banks.

Hovland et al. (1994) assume that the shape of the coral banks is the result of hydrocarbon seepage distribution. Henriet et al. (1998, 2001) interpreted a ring shape of a large number of Magellan mounds, which may argue for a focused venting. If deep-water coral banks were caused by a close, direct link between hydrocarbon seepage along faults, we might expect the coral banks to be strictly lined up along the faults, which is apparently not the case as discussed above. In the detailed 3D and 2D studies of the Magellan mound province (Britsurvey, 1997; Huvenne et al., submitted; McDonnell, 2001) no ring structures has been observed as interpreted by Henriet et al. (1998; 2001) The elongated shape indicates the current direction as illustrated on TOBI sidescan sonar data by O'Reilly et al (2003). These observations argue for an external control of the coral bank development.

In the Belgica mound province some local enhanced reflectors are observed in the top of some of the Neogene-Holocene contourite units. This might indicate a very local and small accumulation of some fluids as gas. However, the gas content in the samples taken on the Thérèse mound, overlying these contourites, is low and in the order of atmospheric values (Jochen Naeth, pers comm.). During the Marion Dufresne coring campaign MD123 of 2001 (Van Rooij et al., 2002) a H_2S smell was reported for one core located on Thérèse Mound. However, follow-up chemical analysis of the core failed to confirm or detect the presence of any H_2S (Jochen Naeth, pers. comm.).

No conclusive evidence is seen in the present day setting between methane seeps and coral mounds formation. Only in the case of the Darwin mounds there seems to be a link between sand extrusion, mound formation and colonisation by deep-sea, cold water corals. However it more than likely that the Darwin mounds are selectively colonised by corals due to their elevated topography and other external factors such as currents and nutrient supply. Nevertheless none of the proposed models provide conclusive evidence regarding the origin of the coral structures because they are based on sparse data. Only further deep drilling will provide a conclusive answer.

The carbonate mounds tend to occur in elongate clusters and are best developed in Irish waters on the banks and along the upper parts of the shelf/slope break. Serprisingly few mound provinces have been located to date in UK waters. However, comparison with the geological/bathymetric setting of the known locations, together with the presence of dredge samples of corals (see Fig. 3) would suggest that mound provinces could be anticipate in the general environs of the Wyville-Thomson Ridge.

What controls coral and mound growth? To date, little is know about the biology and life cycle of *Lophelia pertusa*. For example, when and how often do they spawn? What mechanisms and strategies do they adopt for colonisation? Which of the factors among water temperature, pressure/depth, salinity, turbidity, nutrients or currents are the most important for healthy coral growth? For the limited video footage current direction, erosion (presence/absence), nutrients, turbidity and substrate (hardground/dropstone) seem to be major primary controls. For mound growth, the coral growth pattern (patchy, debris & live) and erosion by deep-sea currents also seem to be the most important parameter.

Conclusions

In the past few years, our knowledge of cold water bioherms has increased significantly. Some of the important conclusions that we draw from this report are:

- Mounds occurring in clusters have been reported from on the eastern, northern Porcupine Seabight, Porcupine Bank, Rockall Bank, northern Rockall Trough, Lorien Bank, Fangorn Bank, Eriador Seamount and Hatton Bank.

- Seabed mounds have been documented on the basis of a variety of seismic, sidescan sonar, video and multibeam bathymetry datasets. Most of the mounds are inferred to be carbonate structures based on seismic data, while a few mounds structures, such as on Lorien Bank, are suggested to be volcanic in origin.
- A greater number and variety of mounds are present, in relatively deep waters of 500 - 1200m, on the continental shelf to the west of Ireland. Surprising, only few large mounds structures have been found to the west of U.K. Further mounds are anticipated in the general vicinity of the Wyville-Thomson Ridge.
- A Plio-Pleistocene age has been suggested based on seismo-stratigraphic correlations for some of the larger mounds in the along the margins of the Porcupine Seabight and Rockall Trough
- Faunal assemblages associated with the large carbonate mounds are primarily composed of cold water corals *Lophelia pertusa*, *Madrepora Oculata*, *Desmophyllum* and stlyasterids.
- During recent video cruises to the carbonate mound sites in the Porcupine Seabight, definite evidence for damage to the mounds and corals due to fishing activity was seen. Lost static fishing gear such as gill nets and trawl marks were observed around the mound sites.
- The nature and origin of the carbonate mounds cannot be described by a simple fault related, hydrocarbon seep and bacterial symbiotic model. Various oceanographic, biological and palaeoclimatic variables and their influence on cold water bioherms and mounds are likely to play a role in the initiation and growth of the carbonate mounds.
- The carbonate mounds and the corals are synonymous with the presence of strong currents. Water stratification and internal tides also appears to be important factors determining the location of the carbonate mounds.

Although we have a better insight of the nature, composition, structure and areal distribution of these seabed mounds, their genesis and formation remains elusive. Primary oceanographic variables such as currents, temperature, salinity and suspended matter most definitely influence the carbonate mounds and cold-water corals. But how have these mounds evolved through time and what initiated their growth in the first place, are all some of the important unanswered questions. Current ongoing research on the samples takes from the mounds should be able to answer some of these questions. Perhaps a more integrated oceanographic, biological and geological approach in addition to drilling is required to fully comprehend the nature and complexity of these seabed features.

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Figures

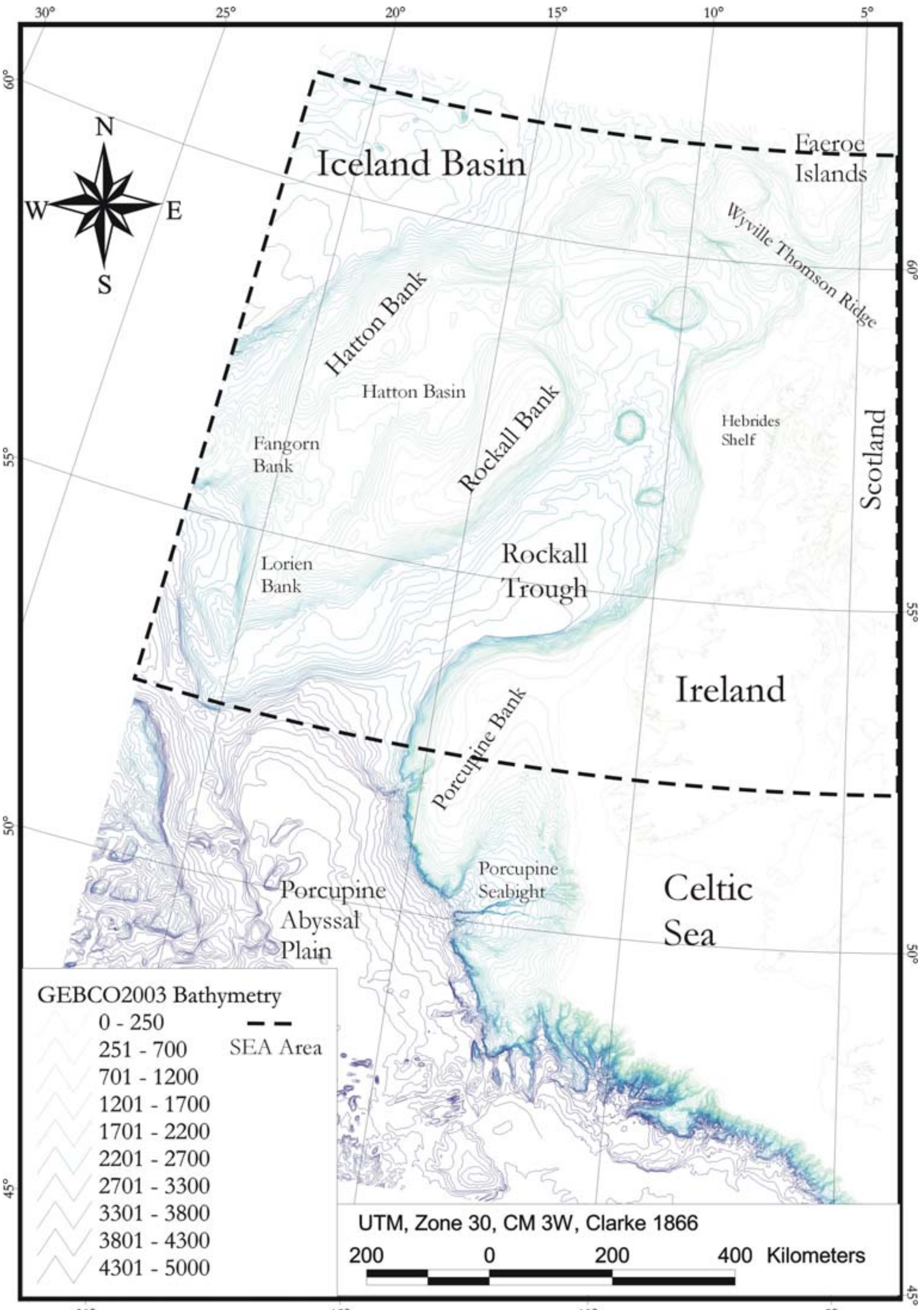

Figure 1: Overview map of the study area highlighting the main bathymetric and geomorphologial features. Bathymetric contours from GEBCO-CE 2003 dataset.

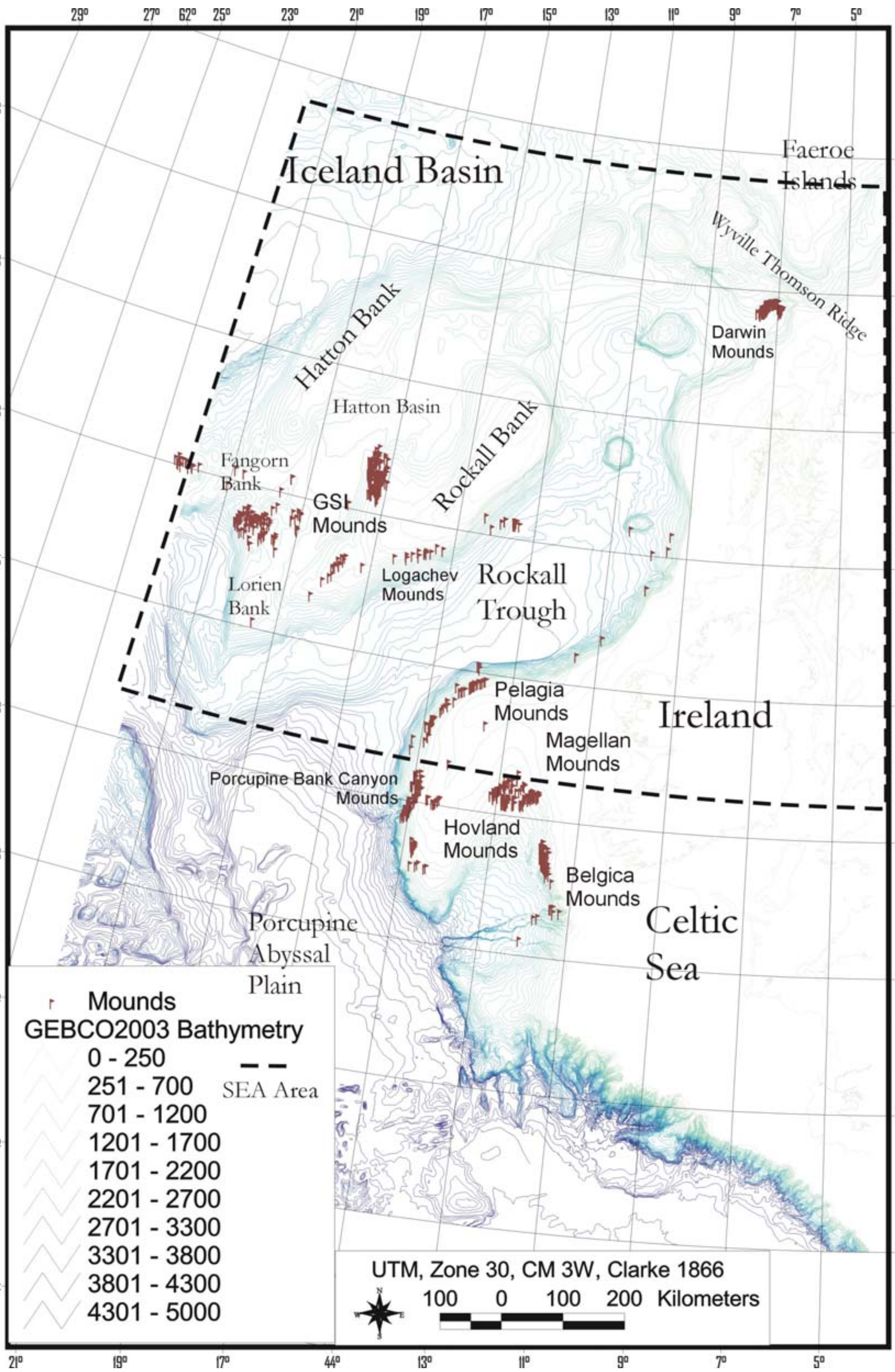

Figure 2: Location of the carbonate mounds in the study area. Mound provinces described in the text are also highlighted.

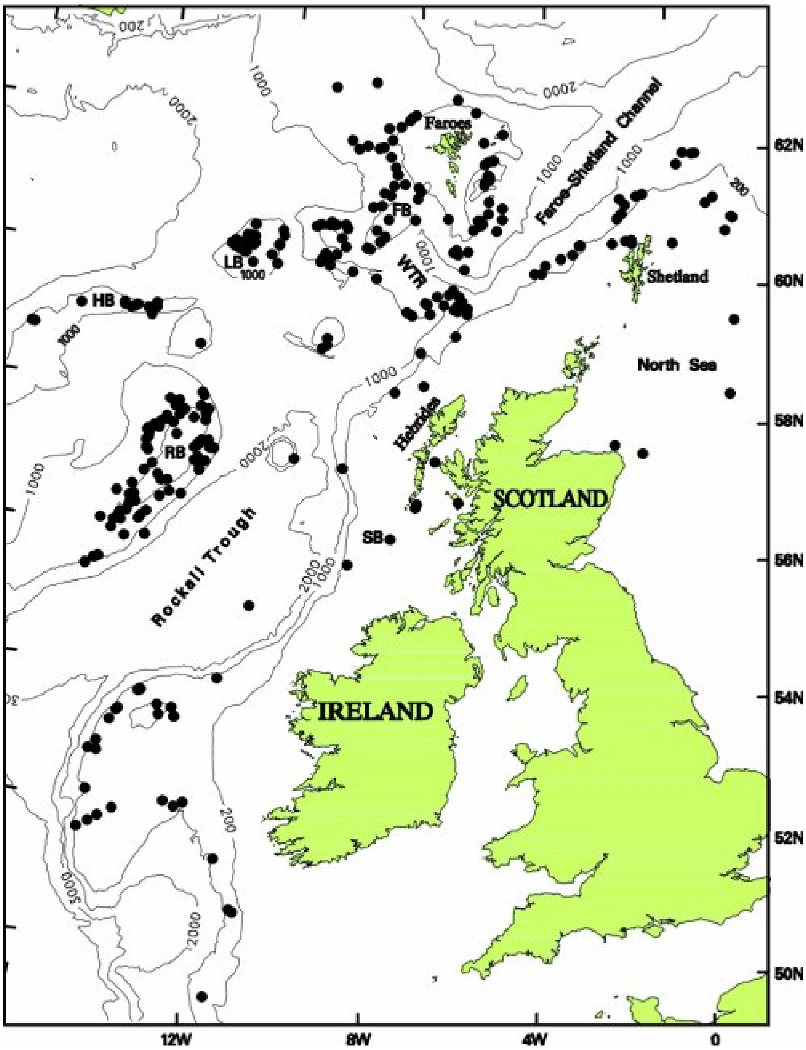

Figure 3: Localities where L. pertusa has been sampled or photographed are shown. Of the trawls hauls, only those <15 km in length have been included as points centred on the mid-point of the trawl track. FB Faeroe Bank; HB Hatton Bank; LB Lousy Bank, RB Rockall Bank; SB Stanton Bank; WTR Wyville-Thomson Ridge. (from: http://www.sams.ac.uk/dml/projects/benthic/lophmap.htm

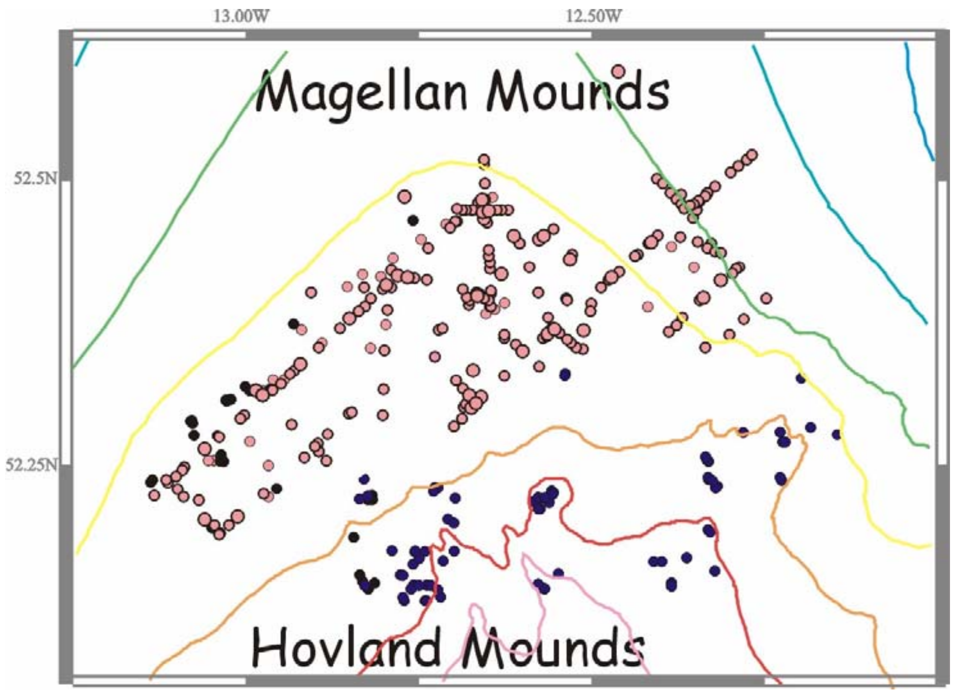

Figure 4: Map from the northern Porcupine Seabight showing the distribution of Hovland surface mounds (black filled circles) and buried Magellan mounds (red filled circles).

Figure 5: High-resolution digital still images from the CARACOLE cruise showing (left) the typical framework reef-building coral species *Lophelia pertusa* and *Madrepora oculata* found on carbonate mounds. The image on the right shows the less abundant solitary coral species *Desmophyllum* (red). Images are copyright IFREMER 2001

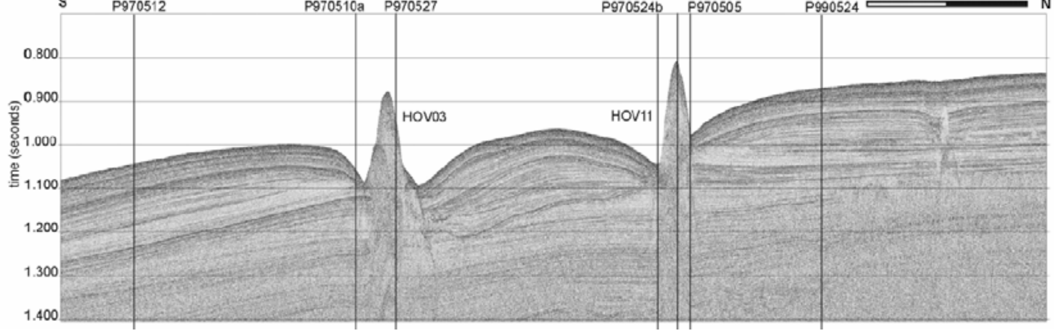

Figure 6: High-resolution seismic profile showing the characteristic shape of the Hovland Mounds in the Porcupine Seabight. Note the presence of a moat or depression surrounding the mounds. Seismic profile from Renard Centre for Marine Geology (RCMG), Gent, de Mol 2001.

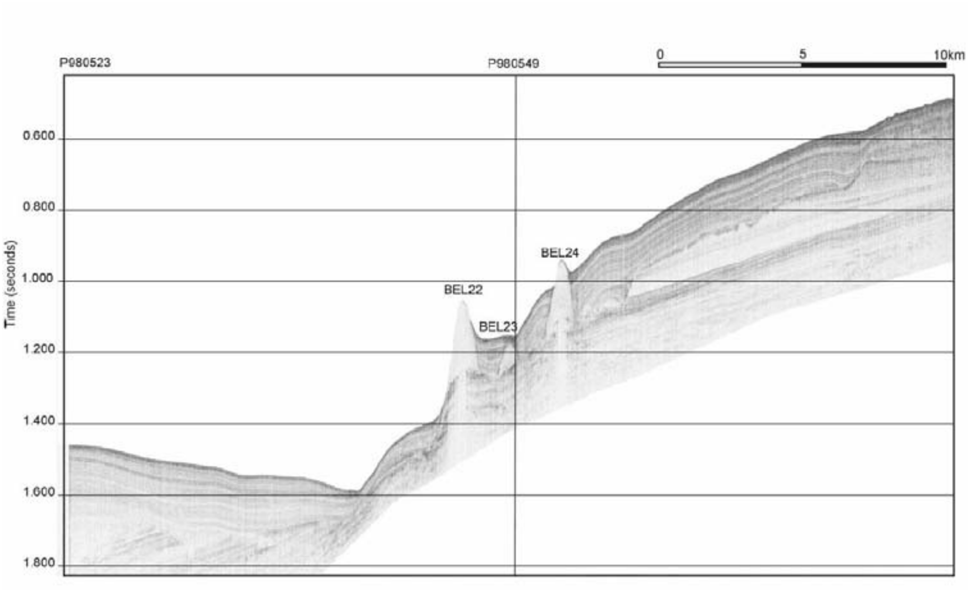

Figure 7: High-resolution seismic profile showing the characteristic shape of the Belgica Mounds on the eastern margin of the Porcupine Seabight. Note the characteristic ponded sediments on the upslope margin. Seismic profile from RCMG, Gent, de Mol, 2001.

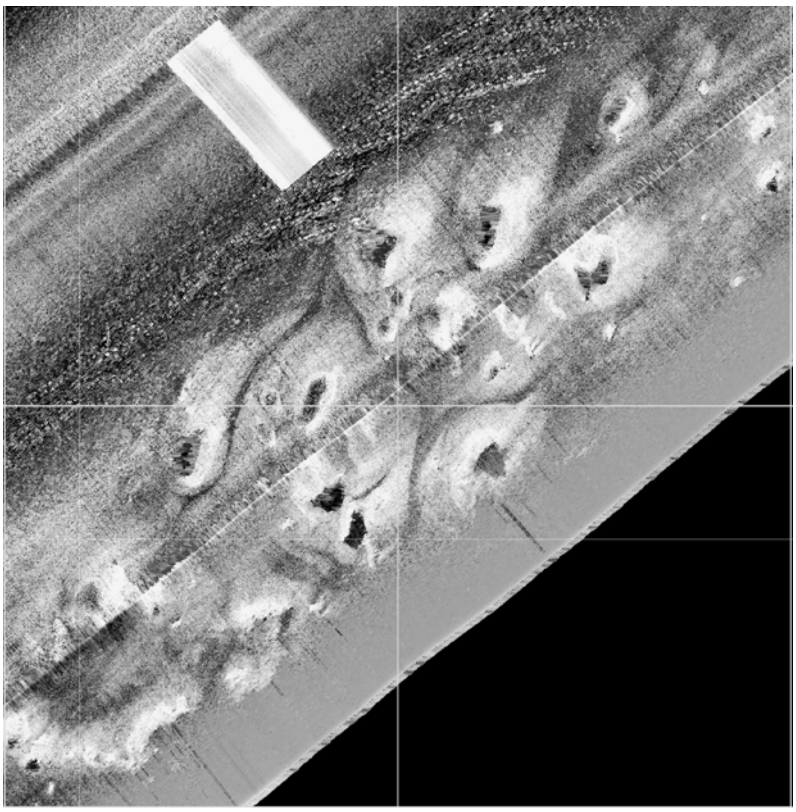

Figure 8: High resolution TOBI sidescan imagery from the northern Porcupine Bank showing the characteristic shapes of Pelagia mounds. (Shannon *et al.* 2001). TOBI swath width approx. 6 km

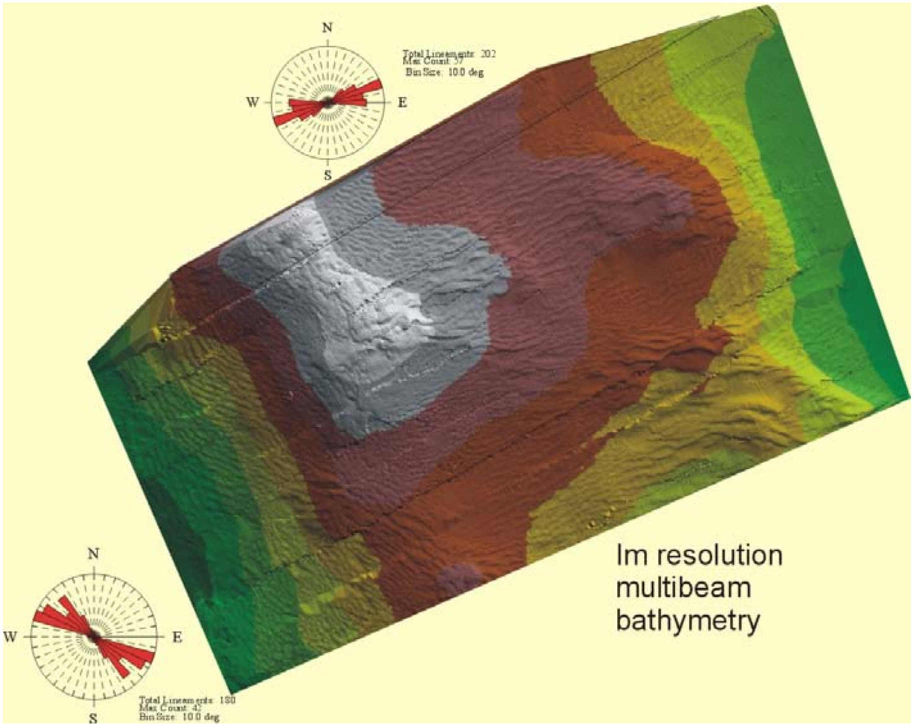

Figure 9: High-resolution multibeam data from the R2 site, Logachev mound province acquired during the CARACOLE 2001 cruise. This image highlights the complex wave structures on the surface of the mound. The mound summit is shown in pink, with sediment wave amplitudes of up to 1m and wavelengths of 2-3m (Unnithan *et al.* 2003)

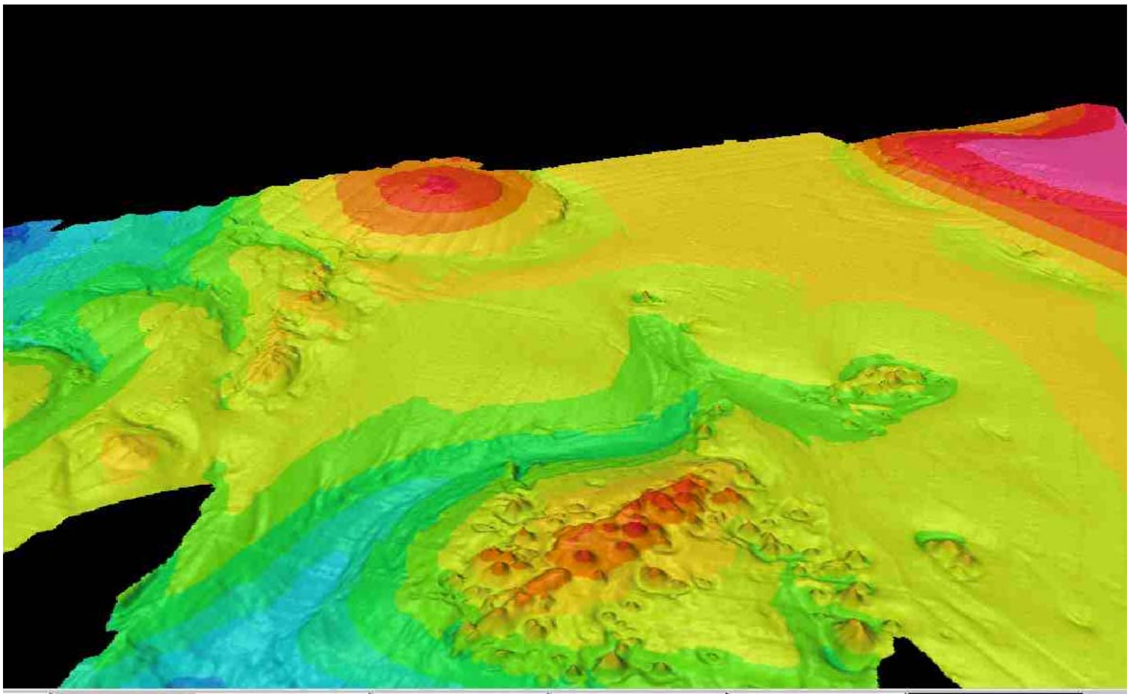

Figure 10: 3-D image, viewing North, of the GSI mound province showing the Fangorn and Hatton Bank with the Edoras Bank Seamount to the west (left in image). The Fangorn Bank is approximately 60 km in diameter (NE-SW orientation, measured along dark green contour) and the mounds are up to 300 m in height.

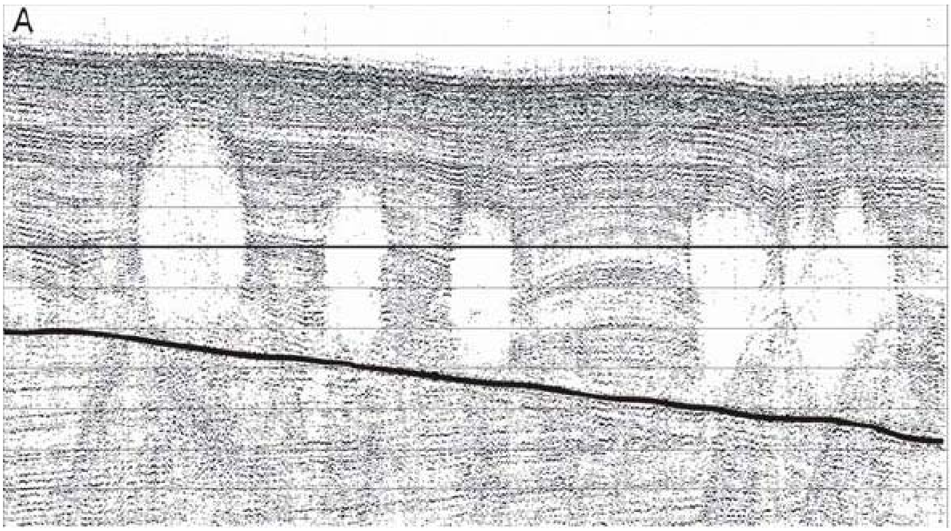

Figure 11: High resolution seismic line over the buried Magellan Mounds. Note these mounds seem to originate (root) from a single horizon. Image spans 300m along the profile and 225 ms TWT along the depth axis.

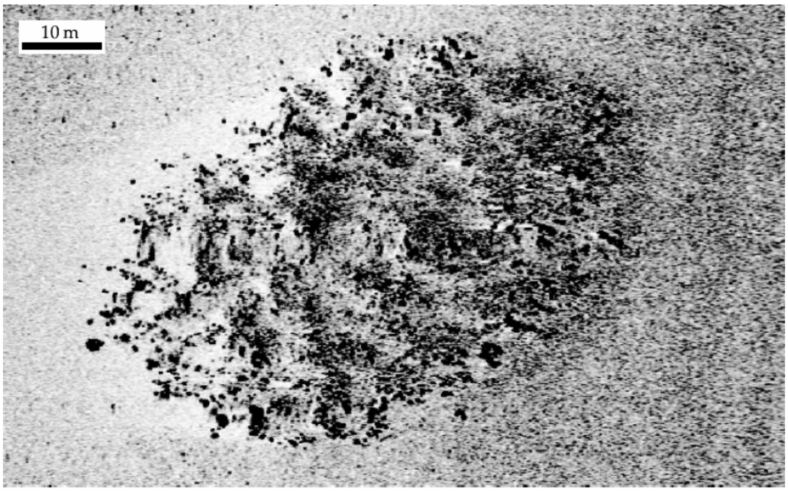

Figure 12: High-resolution sidescan sonar image of the Darwin mounds. Note these mounds are substantially smaller than those in Irish Waters. From Wheeler (2001).

Figure 13: Other mound structures -GLORIA mosaic highlighting high-backscatter patches on the northern margin of the Porcupine Bank (Unnithan, 2001. Commercial high-resolution magnetic data (P. Croker per comms) suggests that these mound structures are volcanic in origin.

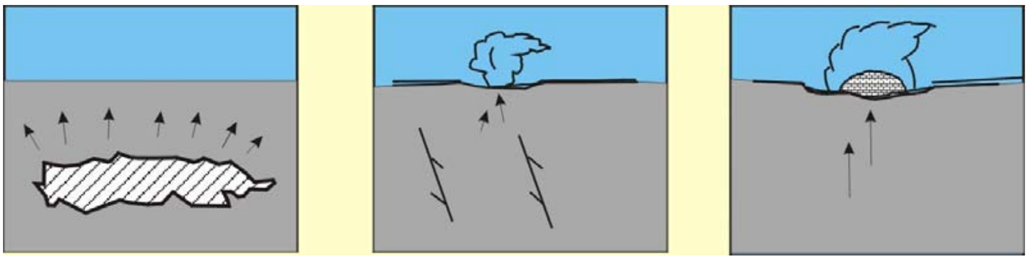

Figure 14: Hovland et al. (1994) suggest a close relation between hydrocarbon seeps and coral bank formation. According to their model, the first condition is that hydrocarbons are generated at depth (A) and that some of them find their way to the surface in a focused manner, through faults and fissures (B). The seabed is here locally eroded by seepage and the local seawater is provided with nourishment on which bacteria and microorganisms depend. Over time, organisms and their skeletal remains accumulate, whereas authigenic carbonates precipitate locally, and cement the sediment and skeletal debris (C).

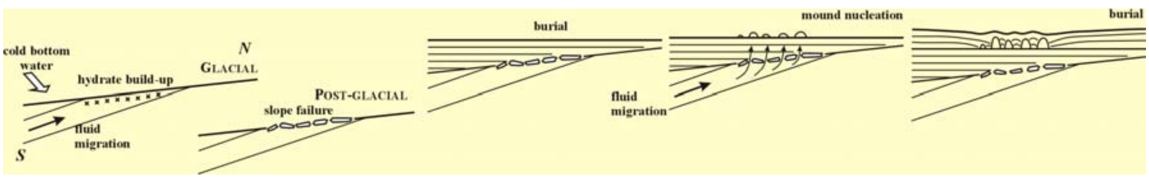

Fig. 15: Henriet et al. (2001) proposed a model for the genesis of the Magellan mounds on a site of episodic fluid migration, under strong varying bottom water temperatures. Under glacial conditions, a horizon of gas hydrates could built up in regions of prolific (even transient) methane flux. Decay of the hydrated horizons could generate slope failure. In renewed methane flux conditions, in warm waters, the disrupted horizon funneled the migrating fluids to the seabed, possibly contributing to venting and mound nucleation.

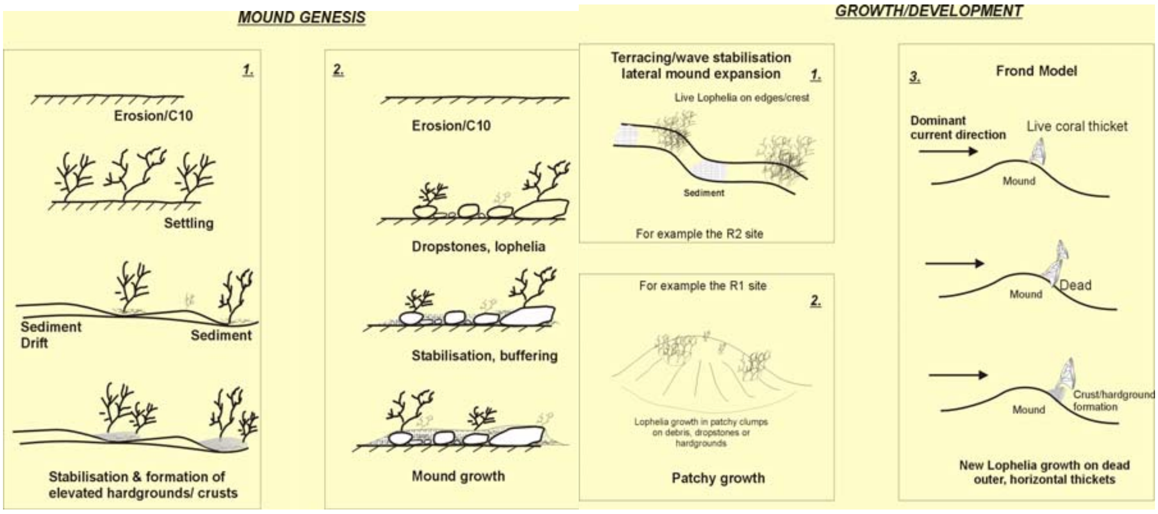

Figure 16: Cartoon sketch showing the sedimentary and oceanographic conditioning model explaining the initiation, growth and development of the carbonate mounds based on video analysis (Unnithan *et al*. 2003).