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RIDGES:
Regionally IntegrateD GEological Mapping of the Celtic Sea

Final Report

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EXECUTIVE SUMMARY

RIDGES forms part of an emerging international research collaboration into the seabed geology and glacial history of the Celtic Sea, building on the 2009 GLAMAR campaign of the Italian r/v OGS Explora. GLAMAR (GLAcial Meltwater and Continental MARgins, IPY EoI 529) was designed to test marine (tidal) versus glacial (meltwater) models for the origin of the seabed ridges that dominate the shelf of the Celtic Sea. The campaign acquired the first seabed geophysical data in over 25 years from the Irish-UK sectors, from a study area where ground-truth is available from BGS vibrocores acquired in the 1970s. The objective of the 1-year RIDGES project was to integrate pre-existing sample and seismic datasets with post-cruise analyses of the GLAMAR dataset. The project involved three main activities: compilation of regional and legacy seabed data; geomorphological mapping of ridges (across the Celtic Sea and within the GLAMAR multibeam dataset); and stratigraphic analysis of newly acquired geophysical profiles. The main outcomes of these activities are:

- the identification of legacy seismic (airgun, sparker, pinger) and sample (grab, vibrocore) datasets acquired in the 1960-80s and held by UK organisations (mainly BGS, also NOCS), including across parts of the Irish sector of the Celtic Sea;
- the identification from regional datasets (Olex bathymetry) of new seabed ridges within the Irish sector, which in addition is shown to include the longest (300 km) and least explored part of the Celtic Sea ridge network;
- the mapping across the ridges within the GLAMAR multibeam area of remarkable transverse bedforms (ribs, crenellations), which extend continuously across the currently accepted limit of glaciation and are inferred to include features present throughout the Celtic Sea previously interpreted as marine bedforms;
- stratigraphic correlation of GLAMAR sparker and Chirp profiles to the existing regional framework and to glacigenic sediments in BGS vibrocores, confirming one ridges to be overlain by glacial till and supporting an interpretation of the transverse ribs as subglacial bedforms.

The results of the project point to the importance of continued research into the glacial to post-glacial history of the Celtic Sea and in particular the potential of the underexplored Irish sector for future investigations involving seabed mapping and targeted vibrocoring. This is reflected in the ship-time applications that were submitted during the project to Eurofleets (SW-ICE) and INFOMAR (GATEWAYS I & II) to acquire additional data in the region. Other spin-offs of the project included training of a research assistant (4 months total) and network consolidation; results were disseminated throughout the project period at national and international meetings.

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1. INTRODUCTION

1.1 Strategic Context

RIDGES forms part of an ongoing international collaboration between researchers in Ireland, Italy and the UK into the seabed geology and glacial history of the Celtic Sea. The project builds on the August 2009 GLAMAR campaign of the Italian research vessel OGS Explora, a contribution to the International Polar Year (IPY) that involved collaboration between OGS (Trieste) and research institutes in Ireland (INFOMAR, NUIM, UCD) and the UK (BGS, NOCS). The 1-year RIDGES project was conceived to facilitate continued collaboration in the post-cruise analysis of the GLAMAR dataset and its integration with pre-existing seabed data from the Irish-UK sectors of the Celtic Sea.

The objective of GLAMAR (GLacial Meltwater and Continental MARgins – IPY EoI 529, Praeg et al. 2005) was to examine a system of seabed ridges that extend across the continental shelf of the Celtic Sea (Fig. 1), long interpreted as moribund tidal sand banks (e.g. Stride 1963a; Scourse et al. 2009) but suspected to be of glacial (glaciofluvial) origin. The 2009 GLAMAR campaign acquired a large set of geophysical data (multibeam data, Chirp and sparker profiles) from a mid- to outer shelf study area that straddles the boundary between the Irish and UK sectors (Fig. 2). The area was targeted due to the availability of legacy seismic and sample data acquired during programmes of offshore mapping in the 1960-80s (Stride et al. 1982; Pantin and Evans 1984; Evans 1990), including a suite of BGS vibrocores containing glacigenic sediments (Figs 1, 2). The GLAMAR campaign yielded the first multibeam seabed imagery across the area, as well as subbottom profiles that afford stratigraphic ties to the vibrocores. The resulting dataset provides the first new information on the morphology and stratigraphy of ridges in the Irish-UK sectors for over 25 years. At a larger scale, complementary information on the distribution of ridges across the Celtic Sea has become available from Olex bathymetry (see below).

The strategic objective of RIDGES is to contextualise and groundtruth the GLAMAR dataset, so as to lay a basis for future investigations of the seabed geomorphology and geology of the Irish-UK sectors of the Celtic Sea. The project is synergic with BGS plans for a new phase of UK offshore Quaternary mapping, and aligns with the INFOMAR goal of integrated seabed mapping and interpretation of the physical features of the Irish coastal and shelf areas, in particular Zone II (50-200 m). Zone II of the Celtic Sea has yet to be explored by INFOMAR and one focus of RIDGES is to explore the potential of the area for further investigations of seabed features in relation to its glacial to post-glacial history.

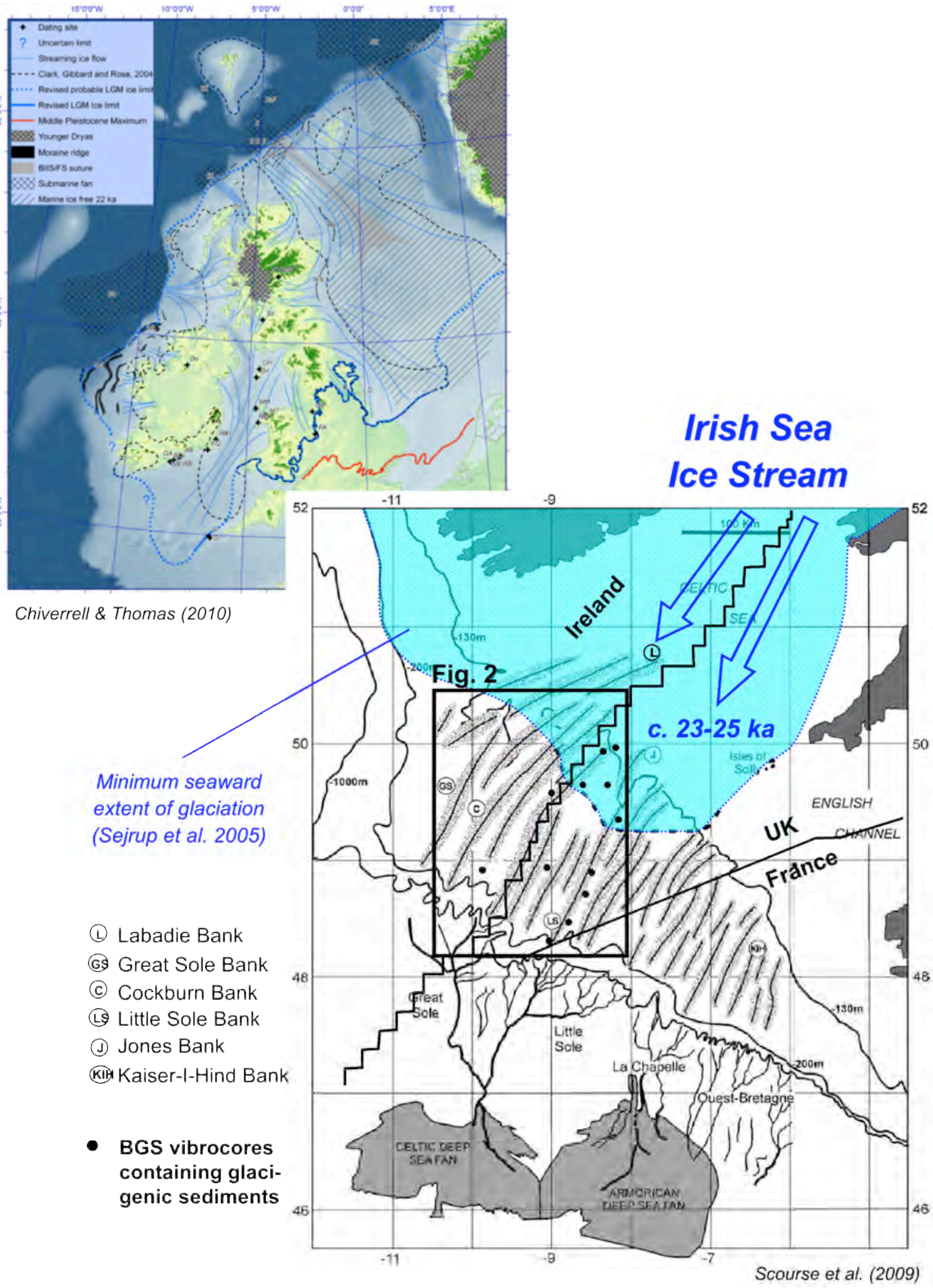


***Figure 1** – Top: summary of evidence on the extent of glaciation of Ireland and Britain, including a late-glacial lobe of the Irish Sea Ice Stream in the Celtic Sea. Bottom: location of the GLAMAR study area (Fig. 2) relative to the seabed ridges (after Belderson et al. 1986) and the suggested extent of glaciation in the Celtic Sea (Sejrup et al. 2005) based in part on the BGS vibrocores containing glacigenic sediments (Scourse et al. 1990). Seabed features across the shelf and slope from Scourse et al. (2009).*

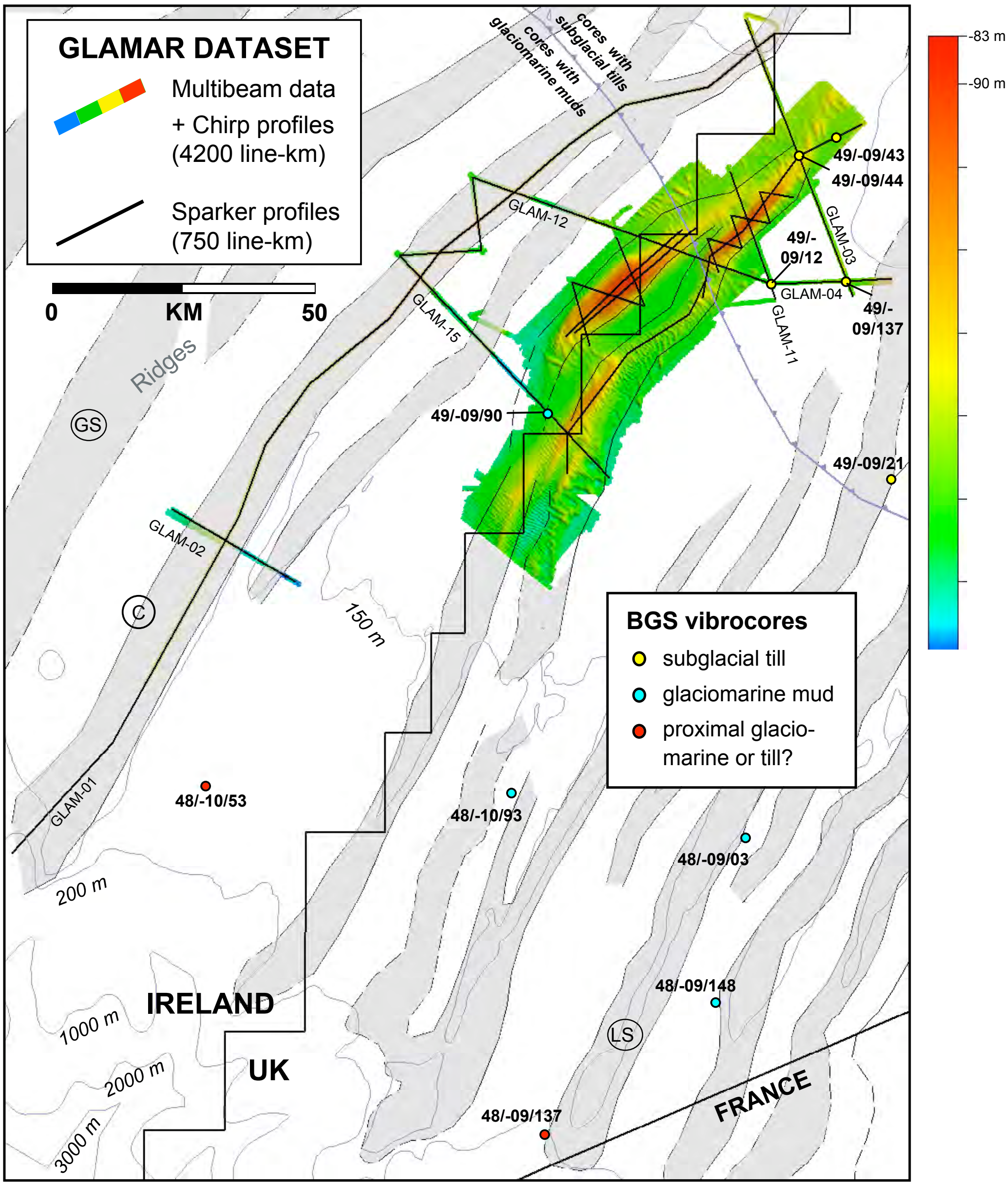


Figure 2 *– Location of GLAMAR geophysical dataset (multibeam, Chirp, sparker) relative to BGS vibrocores acquired in the 1970s that prove glacigenic sediments (see Fig. 1 for location). Ridge distribution mapped from GEBCO 2008 incorporating Olex data (see Figs 3, 10).*

1.2 Scientific Rationale

Reconstructions of the British-Irish Ice Sheet (BIIS) now agree that the ice margin at the last glacial maximum extended well out into the Celtic Sea (Fig. 1; Sejrup et al. 2005; Chiverrell & Thomas 2010; Clark et al. in press). Dating of deposits from the coasts of Ireland and the UK support a short-lived late glacial (c. 25-23 kyr) surge of the Irish Sea Ice Stream (ISIS) southward across the Celtic Sea to reach the northern Isles of Scilly (Fig. 1; Scourse & Furze

2001; O Cofaigh & Evans 2007; McCarroll et al. 2010). The extent of glacial ice to the mid-shelf of the Celtic Sea is confirmed by the recovery west of the Isles of Scilly of subglacial till at the base of several BGS vibrocores (Fig. 1; Pantin & Evans 1984; Evans 1990; Scourse et al. 1990, 1991). The presence of glacimarine sediments at the base of vibrocores farther seaward has been used to postulate an ice grounding line on the mid-shelf (Fig. 1; Scourse et al. 1990; Scourse & Furze 2001). However, it has been noted that the glacimarine sediments could be underlain by glacial tills not penetrated by coring (Sejrup et al. 2005), while glacigenic deposits with "proximal glacimarine or lodgement till affinities" (Scourse et al. 1990) were recovered in two other vibrocores near the shelf edge (48/-10/53 and 48/-09/137, Fig. 1). Thus the maximum extent attained by the BIIS remains uncertain (see Sejrup et al. 2005).

No morphological evidence of an ice limit is recognized on the mid- or outer shelf shelf of the Celtic Sea. The only obvious depositional feature is the system of system ridges, up to 60 m high and c. 10 km wide, that extend over 250 km seaward to meet the shelf edge (Fig. 1). Only the upper parts (<5 m) of the ridges have been cored, indicating a sandy (and sporadically gravelly) character, consistent with observations of internal cross-bedding on seismic profiles (Pantin & Evans 1984; Evans 1990). The ridges lie in water depths of 100-200 m and have long been interpreted as moribund tidal sand banks that formed when sea level was lower (Stride 1963a; Bouysse et al. 1976; Stride et al. 1982; Pantin & Evans 1984; Belderson et al. 1986; Scourse et al. 1990, 1991). This model is supported by numerical modeling of palaeo-tides for lowered sea levels at the last glacial maximum, which are inferred to have been stronger and oriented subparallel to the ridges (Pantin & Evans 1984; Belderson et al. 1986; Scourse et al. 2009). Further support has come from stratigraphic analyses of grids of seismic profiles across the Kaiser-i-Hind bank in the French sector (Fig. 1), which indicate axially downlapping internal strata that are consistent with landward growth of the ridge from a seaward sediment supply during marine transgression (Reynaud et al. 1999a; Marsset et al. 1999). However, these data also reveal sinuous channels along the tops of the ridges (200-600 m wide, with irregular axial profiles) and seabed stratal truncations that are difficult to account for within tidal ridges (Reynaud et al. 1999a; Marsset et al. 1999) and have been used to argue that the ridges are not depositional features but erosional remnants of an originally more continuous sheet-like deposit of estuarine or deltaic sediments (Berné et al. 1998; Marsset et al. 1999).

The current consensus regarding the ridges is that the BIIS reached its late glacial limit in the northern Celtic Sea (Fig. 1) and supplied sediment to an outwash system that, along with sediment delivered by a glacial-stage 'Channel River' or 'Fleuve Manche', was reworked by tidal currents during the post-glacial marine transgression to form the seabed ridges (Bourillet et al. 2003; Lericolais et al. 2003; Reynaud et al. 2003; Scourse et al. 2009). This palaeo-tidal model attributes the main phase of ridge formation to marine transgression of the Celtic Sea c. 20-12 ka (Scourse et al. 2009), after the withdrawal of the BIIS from the Celtic Sea (Fig. 1). The model does not readily accommodate one vibrocore (49/-09/44, see Fig. 2) that proved the flank of a ridge to be overlain by glacigenic sediments (Pantin & Evans 1984; Evans 1990), comprising subglacial till beneath glaciomarine sediments (Scourse et al. 1990, 1991; Scourse & Furze 2001), implying that the ridge existed prior to or during the late glacial advance of the BIIS (Fig. 1). To reconcile this finding with the palaeo-tidal model, it has been suggested either that the inner parts of the ridge system survived overriding by the ice sheet (Figs 1, 2; Scourse et al. 1990, 1991; Scourse & Furze 2001) or that an earlier stage of ridge formation took place syngenetic with the late-glacial surge of the ISIS c. 25-23 ka (Scourse et al. 2009).

An alternative explanation for the origin of the Celtic Sea ridges is that they are of subglacial origin, formed beneath the margin of the BIIS; this was considered by early workers (e.g. Belderson et al. 1986), but discounted due to lack of evidence for widespread glaciation (N. Kenyon, pers. comm.). This idea was reappraised for the GLAMAR project (Praeg et al. 2005), by considering the ridges as potential analogs to broad eskerine features observed in other glaciated areas, composed of glaciofluvial sands and gravels overlain by glacial till. This hypothesis also addresses the internal stratal geometries of the Kaiser-i-Hind bank in the French sector, which are remarkably similar to those of glaciofluvial features formed by meltwater drainage, i.e. eskers and tunnel-valleys (e.g. Praeg 1996, 2003). The 2009 GLAMAR campaign was designed to test the glacial hypothesis, by acquiring geophysical data in a study area along the Irish-UK boundary that crosses both the postulated ice stream grounding line and the sites of key vibrocores containing subglacial till, including 49/-09/44 on the flank of a ridge (Fig. 2). The campaign acquired high-resolution sparker and Chirp profiles along the axes of the ridges and across the sites of key vibrocores containing glacigenic sediments, as well as the first multibeam seabed imagery of ridges in the Irish-UK sectors (Fig. 2). The multbeam data reveal remarkable transverse bedforms (Fig. 2), which preliminary interpretations suggest can be stratigraphically tied to glacigenic sediments in the BGS vibrocores (Praeg et al. 2009).

The scientific interest of the RIDGES project is to further test the glacial model for the origin of the ridges, via more detailed morphological and stratigraphic analyses of the dataset available in the GLAMAR study area (Fig. 2). RIDGES thus follows GLAMAR in addressing first-order questions regarding the formation of the Celtic Sea ridges: are they of post-glacial marine or glaciofluvial origin, and what was the extent and effect of glaciation on the seabed in this area? The answers to these questions have broad implications for the dynamics of the last ice sheet in the area, and for the nature of the sediment deposited across shelf and delivered to the continental slope and deep ocean during glacial-interglacial cycles.

1.3 Report Objectives

The purpose of this report is to present the achievements of the 1-year RIDGES project in the integration of regional and legacy data with the GLAMAR dataset to explore the origin of the Celtic Sea ridges. The project involved three main areas of activity:

- identification and compilation of existing seabed data (with focus on the Irish sector);
- geomorphological mapping (at the scale of the Celtic Sea and the GLAMAR dataset);
- stratigraphic analysis and correlation of GLAMAR profiles to BGS vibrocores.

Project activities within each of these areas are summarized below, following a brief summary of the methods used to visualize and interpret the digital datasets of interest. A preliminary integration of the results then informs a discussion of the origin of the ridges, as well as perspectives on future work. Dissemination activities and spin-offs from the project are summarized in Annexes summarise the use made of project resources to disseminate the results at national and international meetings and to generate spin-offs, including the training of a research assistant and the submission of ship-time proposals.

2. METHODS

Several types of seabed data from the Celtic Sea were used in RIDGES, including regional bathymetric grids, digital versions of seabed map sheets from the Irish-UK sectors, metadata listings of legacy geophysical profiles and sample stations and the GLAMAR geophysical dataset itself. This information was organized and analysed using two main methods:

2.1 Spatial Data Analysis (GIS)

All spatial data (bathymetric grids, seabed maps and seismic/sample locations) were managed within Geographic Information Systems (GIS), with two objectives in mind: compilation of a project database, and seabed geomorphological mapping. The primary software used was ArcGIS, which allowed ready exchanges with other GIS-type systems used for data visualization and/or interpretation (e.g. Global Mapper, Fledermaus). A project database was compiled at NUIM on ArcGIS (see section 3). All systems were used to undertake geomorphological mapping, both at the regional scale of the Celtic Sea ridge system and at the local scale of the GLAMAR dataset (see section 4).

2.2 Seismic Interpretation (SMT)

The GLAMAR high-resolution seismic datasets (Chirp subbottom profiles and sparker profiles) were interpreted using SMT Kingdom Suite seismic interpretation software (http://www.seismicmicro.com/). An academic licence was granted to NUIM for the project, complementary to that held by OGS. The GLAMAR seismic datasets, in SEG-Y format, were loaded into SMT Kingdom Suite software for interpretation and correlation to BGS vibrocores.

3. COMPILATION OF EXISTING DATA

RIDGES brings together four kinds of seabed data available from the Irish-UK sectors, discussed below at decreasing spatial scales: regional bathymetric grids (GEBCO, Olex), 1:250,000 seabed maps (BGS), sample stations and shallow geophysical profiles (BGS, NOCS) and the GLAMAR geophysical dataset itself (OGS). Access to selected BGS data was secured through a 2-year Digital Data Licence (2010-2011); access to NOCS data was arranged courtesy of Neil Kenyon. The different data types are summarized individually below, and all are shown to include information on the seabed of the Irish sector adjacent to the UK borderline.

3.1 Regional Bathymetric Data

Bathymetric grids covering the Celtic Sea were obtained from the GEBCO website (http://www.gebco.net/) and are referred to the GEBCO Digital Atlas (GDA), first published in 1994 and as a revised Centenary Edition in 2003. The most recent version of the GDA (2009) includes two datasets of differing resolution and source data, the GEBCO One Minute and GEBCO_08 grids (http://www.bodc.ac.uk/projects/international/gebco/gebco_digital_atlas/), here referred to as the 2003 grid (1 minute resolution) and the 2008 grid (30 second resolution).

For the Celtic Sea area, the 2003 grid is based on digitised contours that were derived primarily from echosounder profiles acquired by French and UK institutions in the 1960-80s and hand-compiled for GEBCO Sheet G.02 (NE Atlantic off the British Isles; see Hunter 1997). The 2008 grid incorporates Olex bathymetric coverage, comprising single-beam echosounder data recorded along the tracks of vessels that make up the Olex client base, as well as multibeam data available for the Irish offshore (see http://www.olex.no/). The distribution of source data used in GEBCO compilations is not available, but an extract of the current Olex data coverage across the Celtic Sea was obtained as a raster image (courtesy of Christian Wilson, pers. comm. 2010).

The GEBCO 2003 and 2008 data are plotted in Fig. 3 using a colour scale that highlights continental shelf depths above 200 m. The Celtic Sea ridges are resolved by the GEBCO 2003 grid south of approximately 49°30'N, but data quality decreases north of this latitude (Fig. 3a). This reflects the sources of information used for GEBCO Sheet G.02, mainly profiles from the French and UK sectors. In contrast, the GEBCO 2008 grid offers improved resolution of the shelf north of 49°30'N, although some noise remains in the form of spurious banks <100 m deep (Fig. 3b). Comparison with the Olex source data image confirms that most of the spurious banks correspond to gaps in single-beam echosounder coverage (Fig. 3c). The available Olex data coverage within the GEBCO 2008 grid is seen to provide significant additional information on the distribution of the Celtic Sea ridges, in particular in the Irish sector (Fig. 3b).

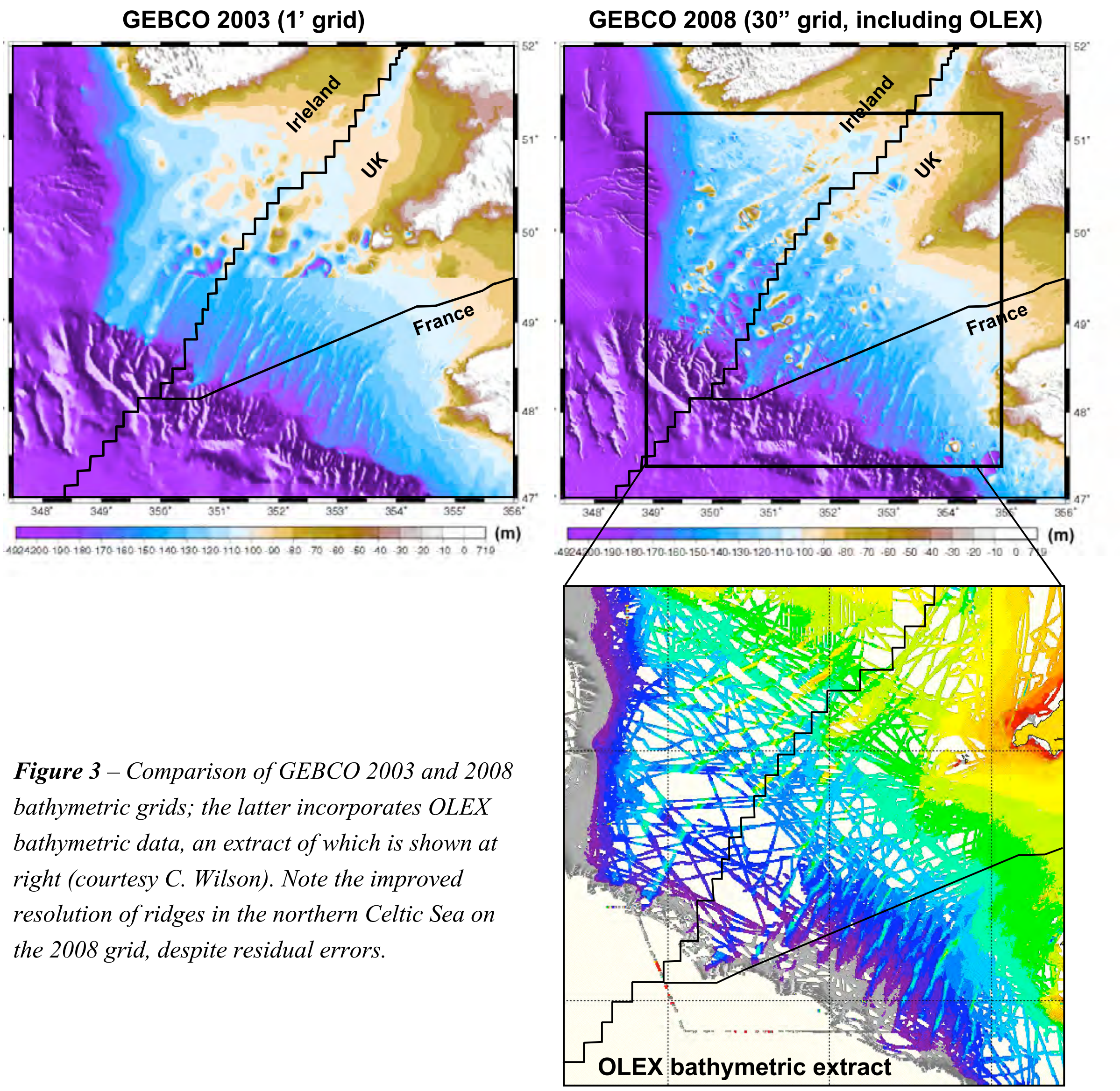
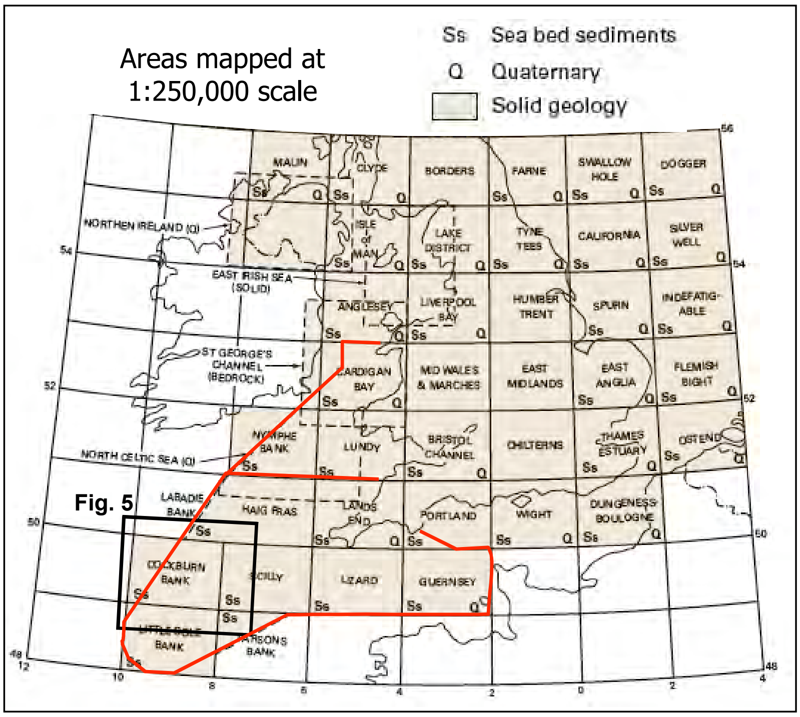


Figure 3 *– Comparison of GEBCO 2003 and 2008 bathymetric grids; the latter incorporates OLEX bathymetric data, an extract of which is shown at right (courtesy C. Wilson). Note the improved resolution of ridges in the northern Celtic Sea on the 2008 grid, despite residual errors.*

3.2 BGS Seabed Maps

The UK sector of the Celtic Sea, and parts of the adjacent Irish sector, were mapped as part of the a 1:250,000 UTM offshore geology series, published by BGS from 1977-1993, which includes themes of Solid Geology (S) and Seabed Sediments with or without Quaternary geology (SBS +/- Q), as shown in Fig. 4. The Solid Geology and Seabed Sediments themes were subsequently digitised and are each available as BGS digital products, while Quaternary maps can be obtained on request as georeferenced scans (see http://www.bgs.ac.uk/products/digitalmaps/addinfo250off.html). Bathymetric contours shown on all maps are available as a separate digital Bathymetry theme.

__Figure 4__ – Offshore coverage of BGS 1:250,000 map sheet series; red lines show the limits of corresponding UK Offshore Regional Reports for the Celtic Sea and southern Irish Sea (Evans 1990; Tappin et al. 1994). Black square indicates the area of interest for GLAMAR/RIDGES (cf. Figs 1,2).



Digital versions of the maps of interest for RIDGES were obtained through the BGS Digital Data Licence. Digital versions of the Solid Geology and Seabed Sediment themes were obtained for parts of four sheets covering the mid- to outer shelf of the Celtic Sea, including the study area (Fig. 4). Quaternary sheets are available to the northeast, prepared jointly by BGS and GSI for the Irish and UK sectors, and scans were obtained of the North Celtic Sea and Cardigan Bay sheets (Fig. 4), with interest in Quaternary stratigraphic units. Results from the mapping of these areas have also been summarised in two BGS Offshore Regional Reports, one including the Celtic Sea (Evans 1990) and another for the area to the northeast (Tappin et al. 1994).

A summary of information from the digital Seabed Sediments maps across the mid- to outer shelf of the Celtic Sea is shown in Fig. 5. The map is based on grab samples of the upper ≤10 cm of seabed sediments. Sediment categories are based on a modified Folk triangle (see Evans 1990), and are seen to form broad patches that grade one into another (Pantin & Evans 1984), although variability in sediment categories across much smaller spatial scales is apparent from bottom photographs (Hamilton et al. 1980). There is a tendency for sandier sediments to occur on the tops of ridges and muddier sandy sediments between them (Hamilton et al. 1980). However, the overall trend across the area is toward muddier sediments to the north, consistent with the observed reduction in tidal velocities across the Celtic Sea (e.g. Stride 1963b; Stride et al. 1982; Hamilton et al. 1980; Evans 1990).

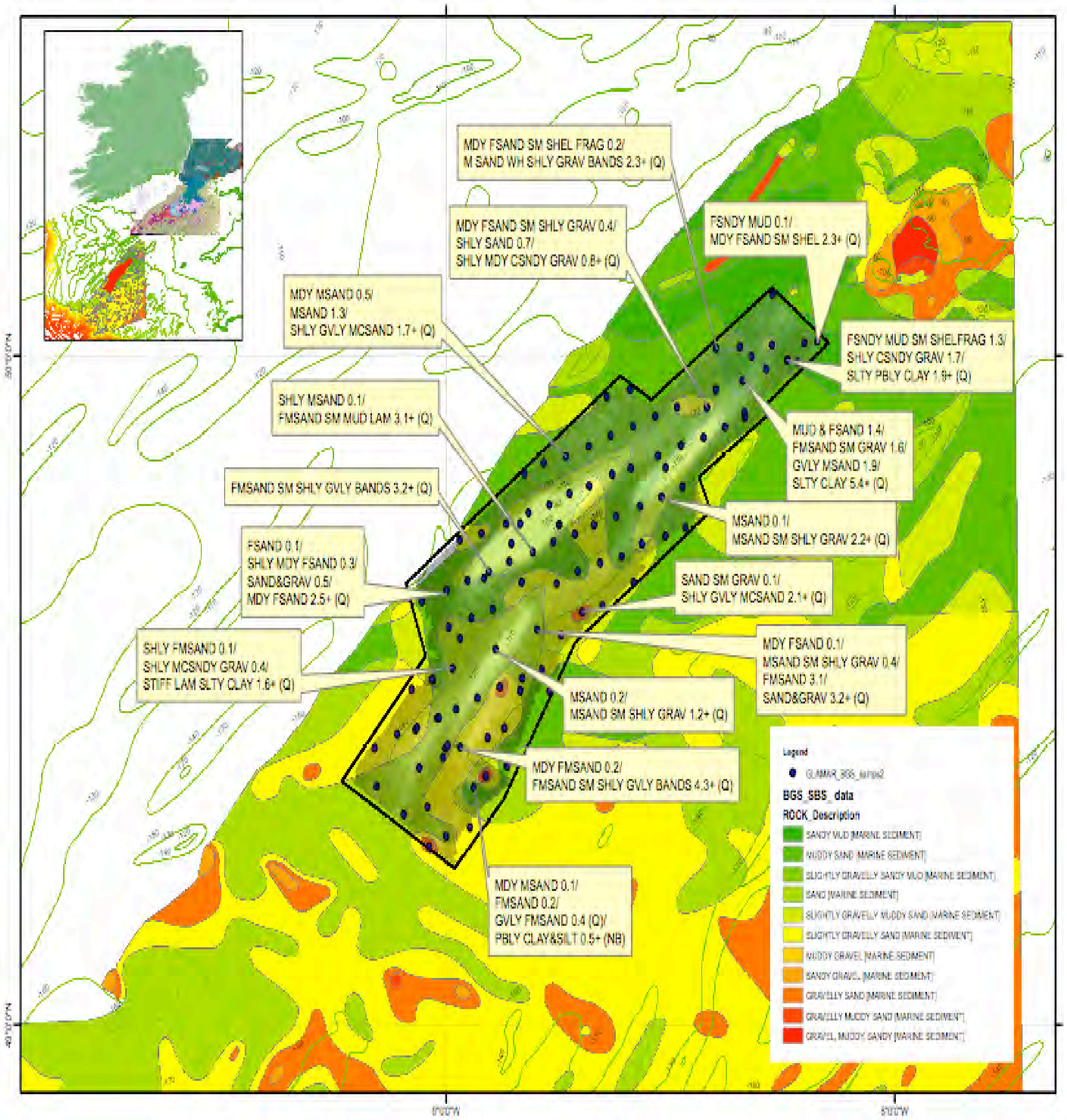


Figure 5 *– Digital version of BGS 1:250,000 Seabed Sediments map sheets for the mid- to outer shelf of the Celtic Sea; location of the GLAMAR multibeam data is shown, along with source sample stations. The locations of BGS Quaternary map sheets to the NW of the study area are shown in the inset.*

Of interest in Fig. 5 are extensive areas of gravelly sediments (sands and/or muds) that extend seaward to the shelf edge. Evidence from cores, bottom photographs and sidescan sonar imagery across the Irish-UK shelf suggest that seabed sediments comprise two main layers: Layer A, mobile sandy sediments (gravelly and/or muddy) locally up to 3 m thick, which overlie Layer B, a coarse sand to gravel pavement (Hamilton et al. 1980; Pantin & Evans 1984; Evans 1990). Layer B has been recognized throughout the Celtic Sea and environs as a strata of well-sorted pebbles and shells, interpreted as a lag formed by winnowing of glacial sediments during marine transgression (Belderson & Stride 1966; Hamilton et al. 1980). However, larger clasts have also been observed across the shelf on bottom photographs and underwater television, including 'rough patches' of cobbles and boulders up to 0.5 m in diameter, confined to mounds up to 1-2 m high (Hamilton et al. 1980). Mounds of similar relief and 5-10 m across are observed in places on sidescan sonar imagery, concentrated in zones 0.5-1 km across (Pantin & Evans 1984). In addition, boulders >1 m in diameter have been recovered on ships' anchors (Scourse et al. 1991). The mounds and rough patches have been interpreted as masses of till-like material, or boulders, deposited across the shelf by ice-rafting (Hamilton et al. 1980; Pantin & Evans 1984; Scourse et al. 1990, 1991).

3.3 Sample Stations (BGS)

The locations of BGS sample stations across the Irish-UK sectors of the Celtic Sea are listed in the BGS Offshore GeoIndex, http://maps.bgs.ac.uk/GeoIndex_Offshore/) and shown in Fig. 6. Hundreds of stations were occupied from 1972-1989, most resulting in both Shipek grab samples and vibrocores (up to 5.4 m long). Metadata on 150 stations acquired from 1977-79 in and adjacent to the GLAMAR study area, within the box in Fig. 6, are listed in Appendix A. Many of these (59/150) lie in the Irish sector, up to 75 km west of the boundary line (Fig. 6).

Additional information on selected stations within the RIDGES area of interest was requested through the BGS Digital Data Licence. Phase 1 of the request yielded scanned copies of the field logs of 29 vibrocores: 12 reported to contain glacigenic sediments (Fig. 1; Scourse et al. 1990) and 17 others within the area of GLAMAR multibeam coverage. Information from the field logs for all 29 vibrocores is summarized in Appendix B, along with an example of a field log. The field logs contain brief written descriptions of the cores, but no graphic logs.

The field logs also provide information on station positions and depths. Sample stations were positioned using the Decca Navigator System (DNS). It is not known whether sample depth was measured acoustically or by length of cable. The depths are not corrected for tidal variation, which is up to 4 m in the area. In Appendix B, the depths from 14 of the field logs are compared to depths measured from the GLAMAR multibeam DTM. Most of the field logs indicate shallower depths (by up to 27 m), while two indicate greater depths (by up to 14 m). Most of the errors (8/14) are less than 6 m and would require only minor modifications of position to correct; others would require changes in position of up to several kilometers. This assumes that the measured depth is not itself in error. Thus the indicated DNS positions of the stations are likely to have errors that cannot presently be well constrained.

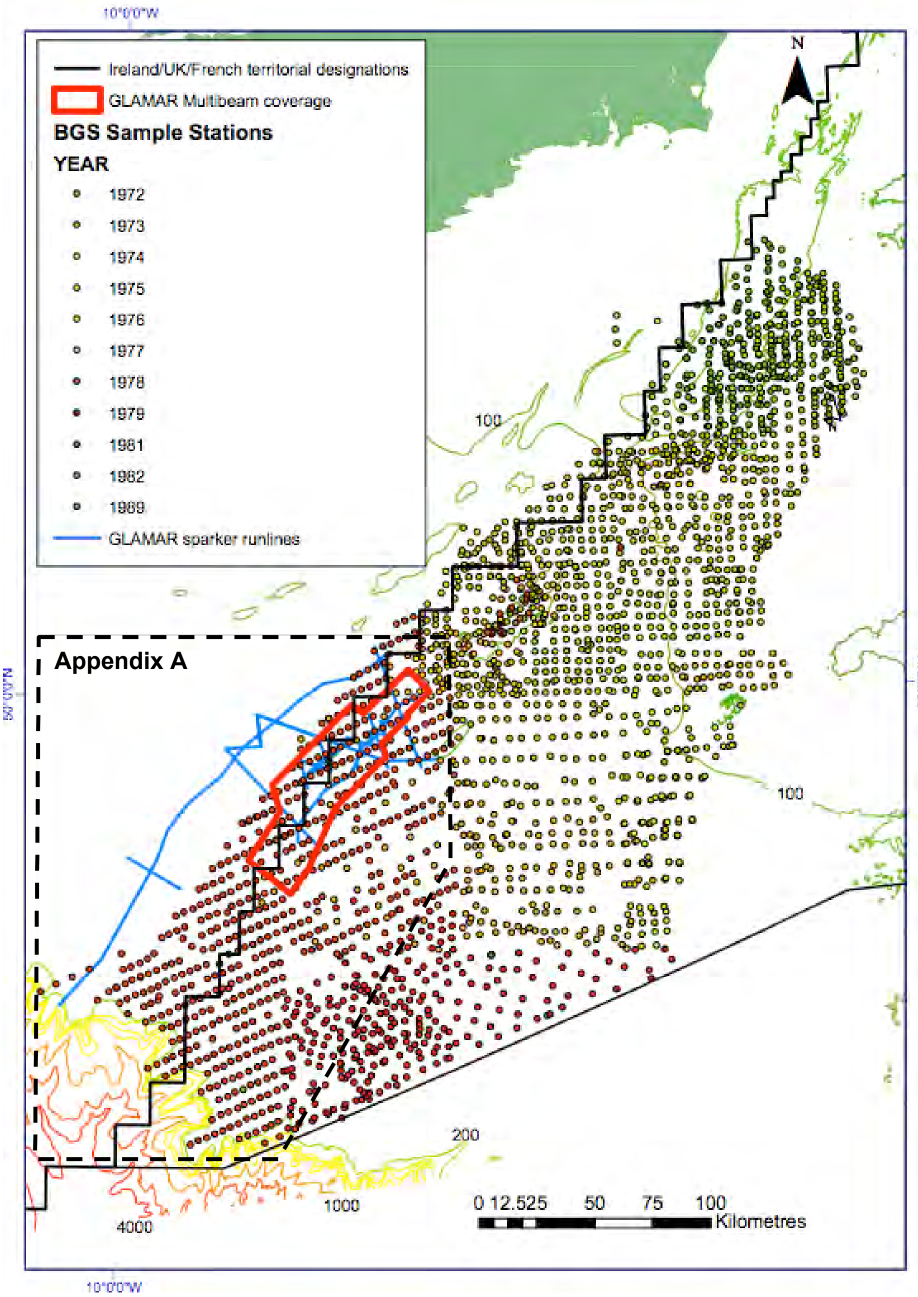


Figure 6 *–Distribution of BGS sample stations (grabs, vibrocores) across the Irish-UK Celtic Sea; stations within the dashed area are listed in Appendix A.*

Additional information has been published on the 12 vibrocores containing glacigenic sediments (Pantin & Evans 1984; Scourse et al. 1990, 1991), which appear to have been identified for study from the field logs. No information has been published on other vibrocores from the Celtic Sea, beyond general references to the recovery of sandy sediments (Pantin & Evans 1984; Evans 1990). This is consistent with the field logs from the 17 non-glacigenic vibrocores in the GLAMAR study area (up to 4.26 m long), which all indicate recovery of sandy sediments (Appendix B). The vibrocores themselves are held in archive at BGS Edinburgh.

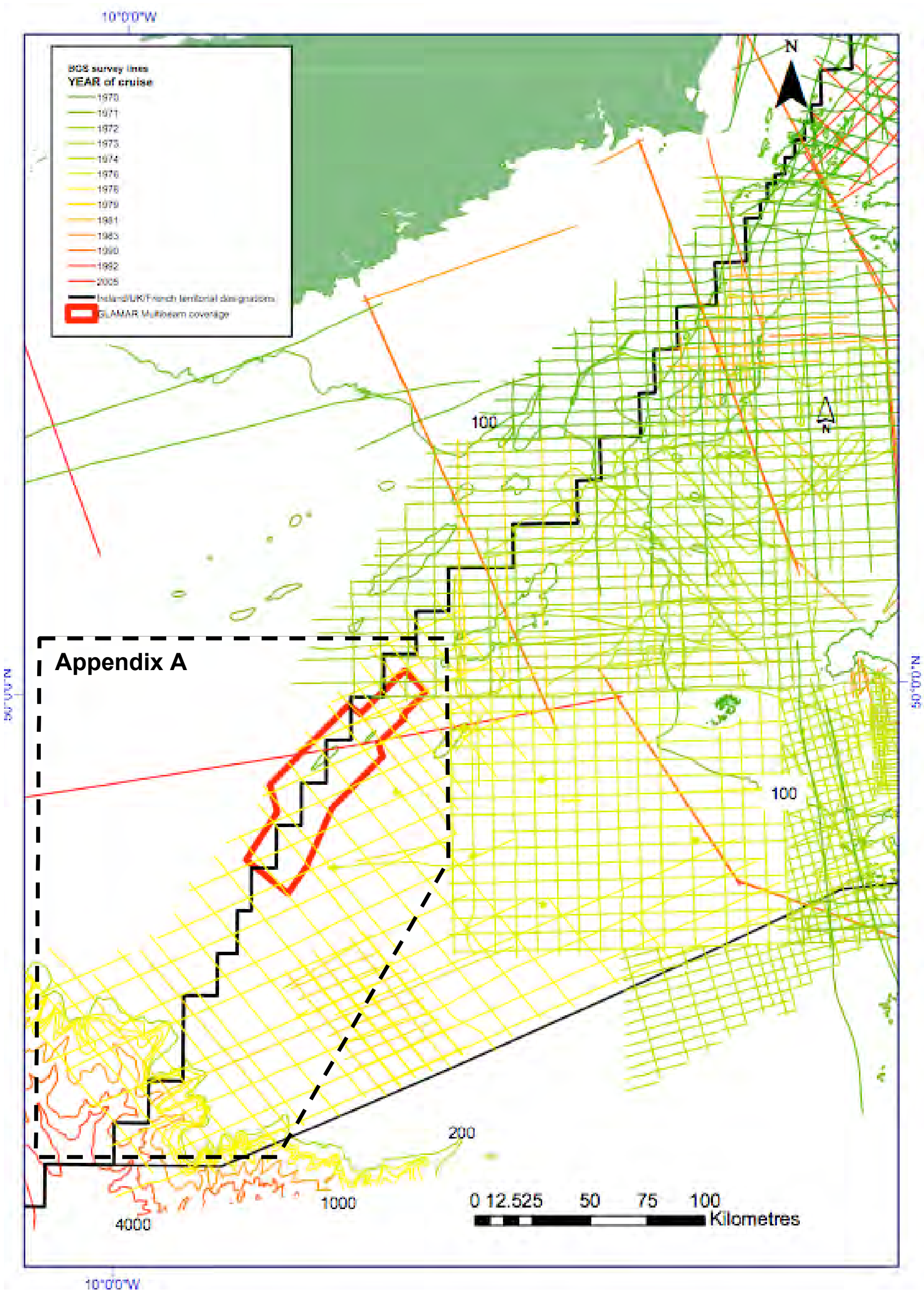


***Figure 7** –Distribution of BGS geophysical profile lines (airgun, sparker, pinger) across the Irish-UK Celtic Sea; lines within the dashed area are listed in Appendix C.*

3.4 Geophysical Profiles (NOCS, BGS)

The locations of shallow geophysical profiles identified across the Irish-UK sectors of the Celtic Sea are shown in Fig. 7. Metadata on profiles crossing the GLAMAR study area, within the box in Fig. 7, are given in Appendix C. The 42 profiles total over 5500 km, of which over 2200 km cross the Irish sector. All were acquired as paper records, held in archive by NOCS and BGS.

The first geophysical profiles across the Celtic Sea were acquired in the 1960s during campaigns of the then National Institute of Oceanography (NIO), now NOCS. The track-lines of most of these campaigns have not been digitised; those shown in Fig. 7 were digitised during RIDGES from scanned copies of the original field sheets, obtained from NOCS courtesy of Neil Kenyon and Gavin Elliott. The profiles were acquired in 1962 during the Kerry cruise of the RRS Discovery II using one of the earliest Boomer systems (Bowers 1963; Stride 1963a).

Grids of profiles were subsequently acquired by BGS in the 1970s (see also the Offshore GeoIndex, http://maps.bgs.ac.uk/GeoIndex_Offshore/). This includes a grid profiles across the mid- to outer shelf acquired in 1978-1979 that extend up to 100 km into the Irish sector. The multi-parameter profiles were run using up to three sound sources, so that each line may include airgun, sparker and pinger (see Appendix C).

Scanned images of selected BGS sparker and pinger profiles were obtained through the Digital Data Licence (listed in Appendix C); scanned images of the 1962 boomer records were obtained from NOCS (courtesy of Peter Miles and Martin Saunders). Examples of each type of profile are shown in Fig. 8 and are seen to provide useful information on the internal structure of the ridges and their relations to subjacent and adjacent sediment units. Sparker and boomer profiles both provide information up to the first seabed multiple at 100-200 ms, while pinger profiles provide subbottom penetration of up to 20 ms.

3.5 GLAMAR dataset

The GLAMAR geophysical dataset (Fig. 2) comprises 750 km of sparker profiles acquired on selected tracks, and c. 4200 km of Chirp subbottom profiles and multibeam data acquired along all tracks, the latter including complete coverage of a c. 100 x 25 km area. The 22 sparker profiles acquired are listed in Appendix D, along with the 212 associated Chirp profiles.

The sparker profiles provide information above the first seabed multiple at c. 100-200 ms, the Chirp profiles up to 20 ms penetration, similar to the 1970s BGS sparker and pinger data (Fig. 8). Chirp penetration depended on conditions (sea-states to force 7-8 in the later part of the survey); thus of 212 profiles acquired, only 111 yielded useful subbottom information (listed in Appendix D). All sparker and Chirp profiles were converted to SEG-Y format aboard ship to facilitate loading into SMT Kingdom Suite.

Multibeam data were processed aboard ship and at OGS using PDS2000 software to obtain DTMs of 10-30 m resolution that were used for RIDGES. Unfortunately, it was not possible to resolve problems with PDS2000 in order to obtain a backscatter mosaic for use in RIDGES.

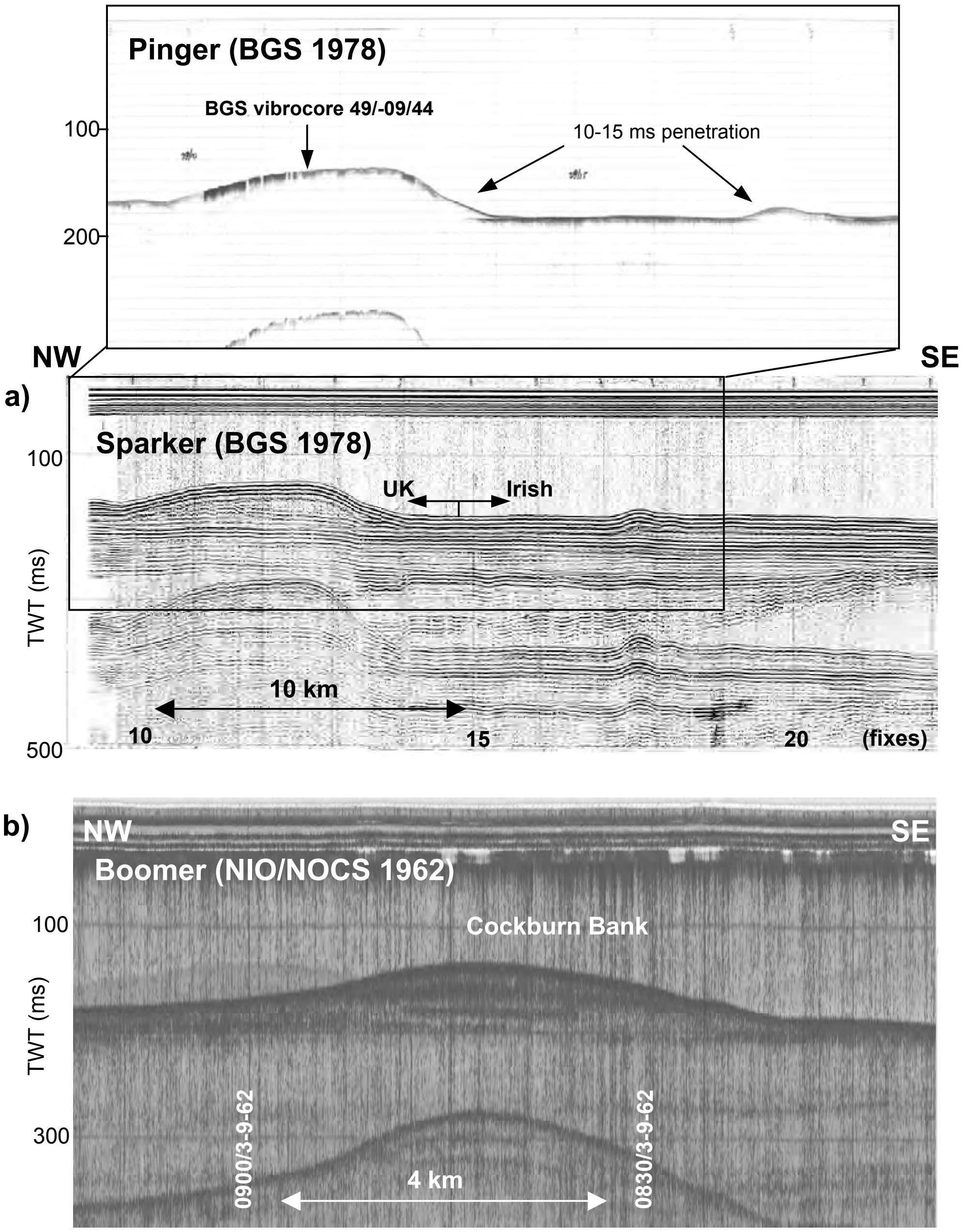


Figure 8 *–Examples of legacy data across ridges in the Irish-UK sectors: a) BGS sparker and pinger profiles (line 1978_4_29) across the GLAMAR multibeam area; b) a 1962 boomer profile across Cockburn Bank. Note internal reflections within ridges on the boomer and sparker profiles.*

4. GEOMORPHOLOGICAL MAPPING

Geomorphological mapping of seabed features was undertaken at two scales: of the ridge system across the Celtic Sea (with particular attention to the underexplored Irish sector); and of bedforms newly recognized within the GLAMAR multibeam mosaic.

4.1 Celtic Sea ridge system

A map of the entire Celtic Sea ridge system was first presented by Stride et al. (1982), as lines on the axes of the ridges (Fig. 9a). A slightly modified version of the same map is shown in Fig. 1, presented by Belderson et al. (1986) and reproduced by recent authors including Scourse et al. (2009). The axes of the ridges were drawn based on echosounder and shallow seismic profiles across the Celtic Sea acquired by the then UK Institute of Ocean Sciences (now National Oceanography Centre, Southampton - NOCS), which formed part of the input to the eventual GEBCO 2003 grid (Fig. 3a).

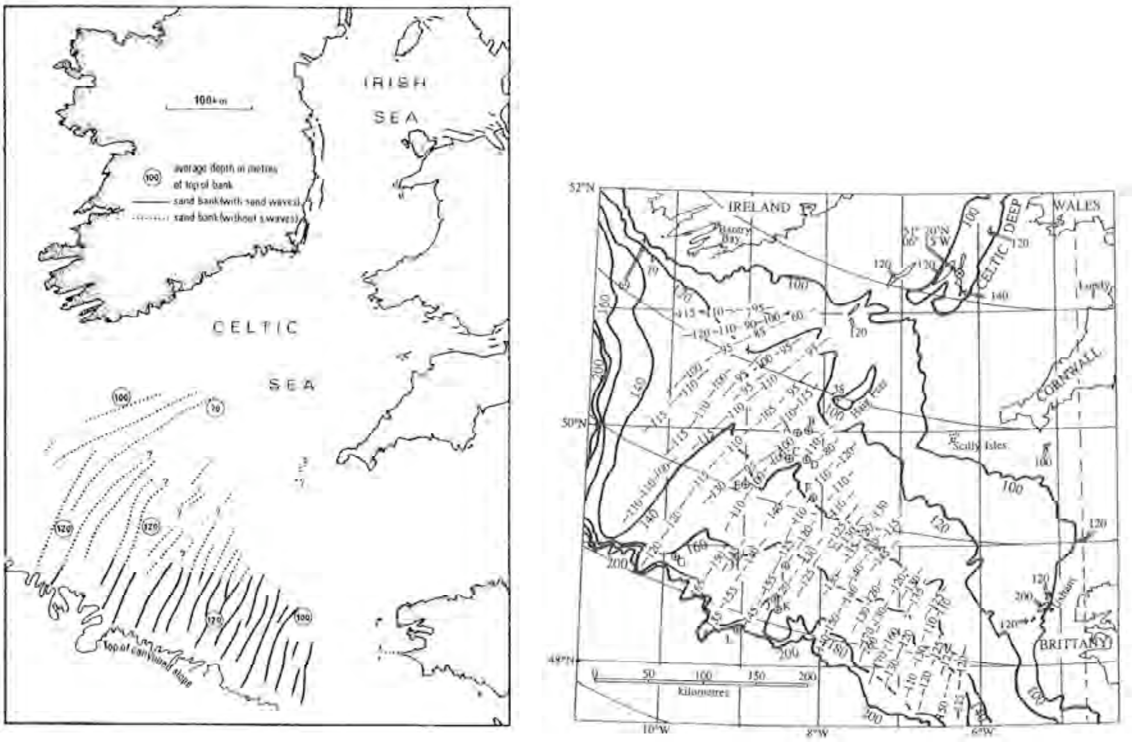


Figure 9 *– a) first map of the Celtic Sea 'sand bank facies', as axial lines, from Stride et al. (1982), cf. Fig. 1; b) map of ridge axes and minimum crestal depths compiled by Wingfield (1995).*

More detailed bathymetric mapping of the ridges has taken place separately in the UK and French sectors (e.g. Bouysse et al. 1976; Pantin & Evans 1984; Evans 1990), but has not resulted in an improved bathymetric map of the entire ridge system. An updated map of the ridge axes was presented by Wingfield (1995) using all information available at the time and includes two previously unidentified ridges to the north in the Irish sector (Fig. 9b).

The distribution of the Celtic Sea ridges was remapped during RIDGES using the GEBCO 2008 grid incorporating Olex bathymetric data, with reference to an image of the original Olex dataset (see Fig. 3). The results are shown in Fig. 10, as axial lines plus lines drawn along the edges of the ridges. Comparisons with earlier maps (Figs 1, 6) show differences in the extent and morphology of the ridges, particularly in the Irish sector.

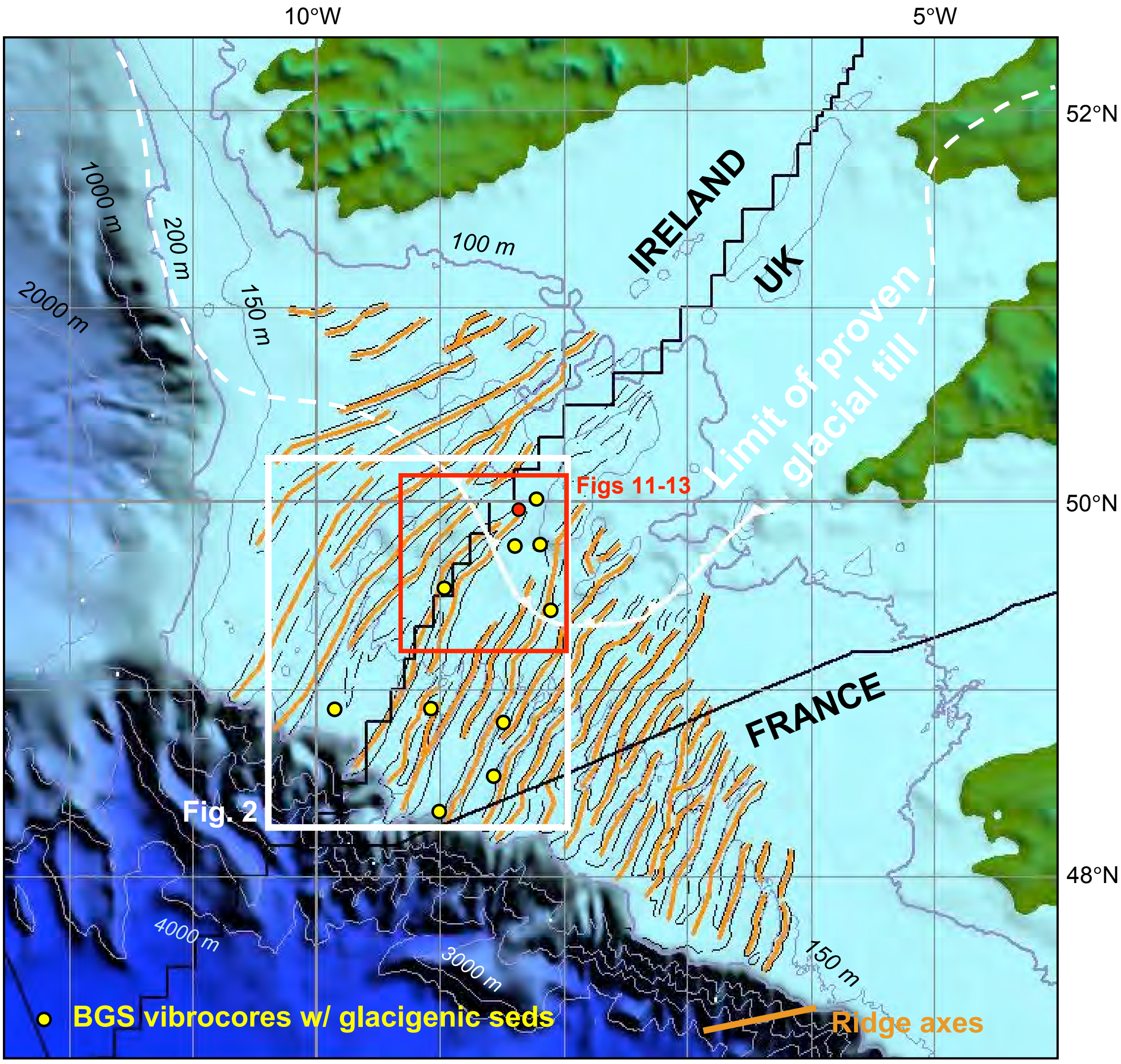


Figure 10 *– Distribution of seabed ridges in the Celtic Sea, remapped using GEBCO 2008 and an extract of the Olex bathymetry (see Fig. 4). White box indicates GLAMAR/RIDGES study area (cf. Fig. 2), red box indicates area of GLAMAR multibeam coverage (see Figs 11-13).*

The greatest differences from earlier maps are apparent in the Irish sector, where there are modifications to existing ridges, as well as several new smaller ridges in the north, as near as 50 km to the Irish coast (Fig. 10). The new ridges in the Irish sector emphasise the fan-like nature of the network as a whole, pointing to an imaginary apex in the north Celtic Sea. The ridge network extends seaward toward c. 600 km of the shelf edge of the Irish, UK and French sectors, and is seen to reach its maximum cross-shelf width of 300 km in the Irish sector. It is not clear from the available data whether ridges in the Irish sector extend to the shelf edge of the Porcupine Seabight, although two appear to deflect to the southwest, parallel to ridges farther south. South of the Gobal Spur, ridges in the Irish and UK sectors extend to the shelf edge, whereas those in the French sector terminate inboard of the shelf edge, which is occupied by broader, fan-like areas of lower, irregular relief (e.g. Bouysse et al. 1976).

Another difference from earlier maps is that seaward convergences are more common across the ridge network, along with apparent divergences in the Irish sector (and one in the French sector) (Fig. 10). It is not always clear whether convergent/divergent ridges actually meet, or one ends/begins near the other. Such morphologies complicate estimates of the spacing of the ridges, previously suggested to be 16 km in the French sector and broader to the north (Bouysse et al. 1976; Pantin & Evans 1984). Nonetheless, the average spacing along a line across the central part of the network in the French and UK sectors (280 km / 19 ridges = 15 km) is less than in the Irish sector (180 km / 10 ridges = 18 km). Many of the ridges of the Irish sector also appear broader (up to 10 km) than those to the southeast. The spacing of the ridges is at the upper limit of known tidal sand banks (e.g. Off 1963), and the ridges differ by being up to one and a half times higher and up to twice as wide (Stride 1963a).

4.2 GLAMAR multibeam area

The GLAMAR multibeam data provides the first seabed imagery of the ridges in the Irish-UK sectors, across a 100 x 225 km area encompassing parts of two main ridges (Fig. 11). Bathymetric and slope maps (Figs 11, 12) reveal three types of bedform, at decreasing spatial scales: ridge segments, transverse ribs and superimposed crenellations. The mapped distribution of these bedform types is shown in Fig. 13 and they are discussed individually below. The bedforms extend across the postulated limit of glaciation, up to 65 km to the SW (Figs 11-13).

4.2.1 Ridge segments

The ridges in the GLAMAR area are seen to be composed of shorter segments, each an isolated high, offset from each other in an approximate en echelon pattern (Figs 11-13). This pattern has been previously noted in the Irish-UK sectors (Stride 1963a), including for the two main ridge segments in the north of the area (see Pantin & Evans 1984), which are up to 40 km long, 7 km wide and 60 m high (Fig. 11). However, what was thought to be a single ridge in the south is now seen to be subdivided into three smaller segments, each tens of kilometers long (Fig. 13).

The ridges have very low slopes, reaching a maximum of 1.5° on their flanks (Fig. 12). This is somewhat greater than the slopes of 0.5-1° previously reported, but remains much less than the slopes of active tidal sand banks worldwide (Stride et al. 1982).

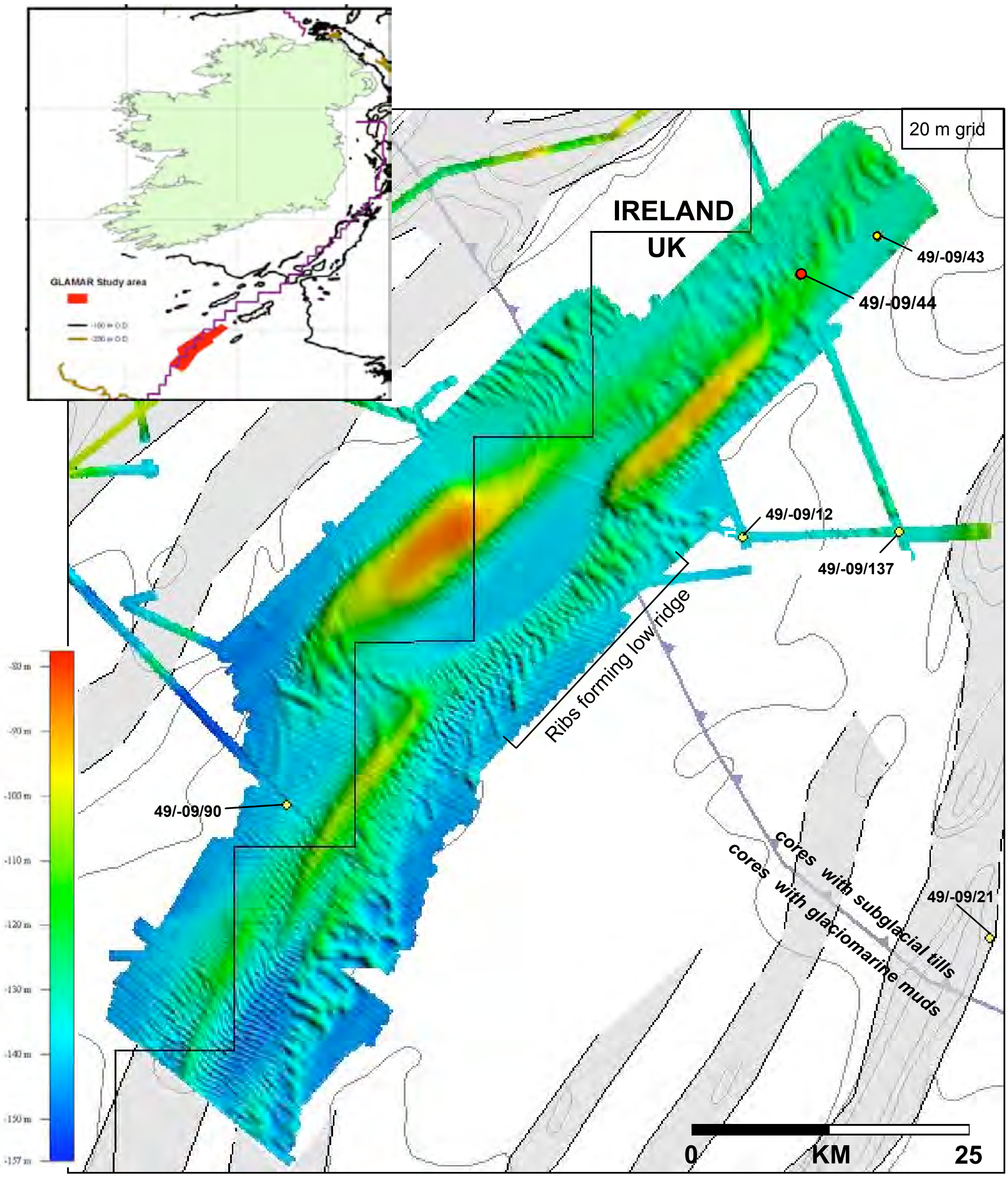


***Figure 11** – GLAMAR multibeam mosaic at a 20 m grid (cf. Fig. 2).*

4.2.2 Transverse Ribs

The ridge segments are seen to be flanked by, or give way laterally and axially, to arcuate transverse ribs up to 10 m high, hundreds of metres wide and up to 10 km in length (Figs 11-13). In one case, two ridge segments are joined axially by a set of ribs of comparable width (3-5 km) that in cross-section appear to form a low ridge (Fig. 14).

Two forms of rib are distinguished, larger and smaller (Figs 13-15). Larger ridges are up to 10 m high and have irregular or 'blobby' plan-forms associated with varying orientations, widths and

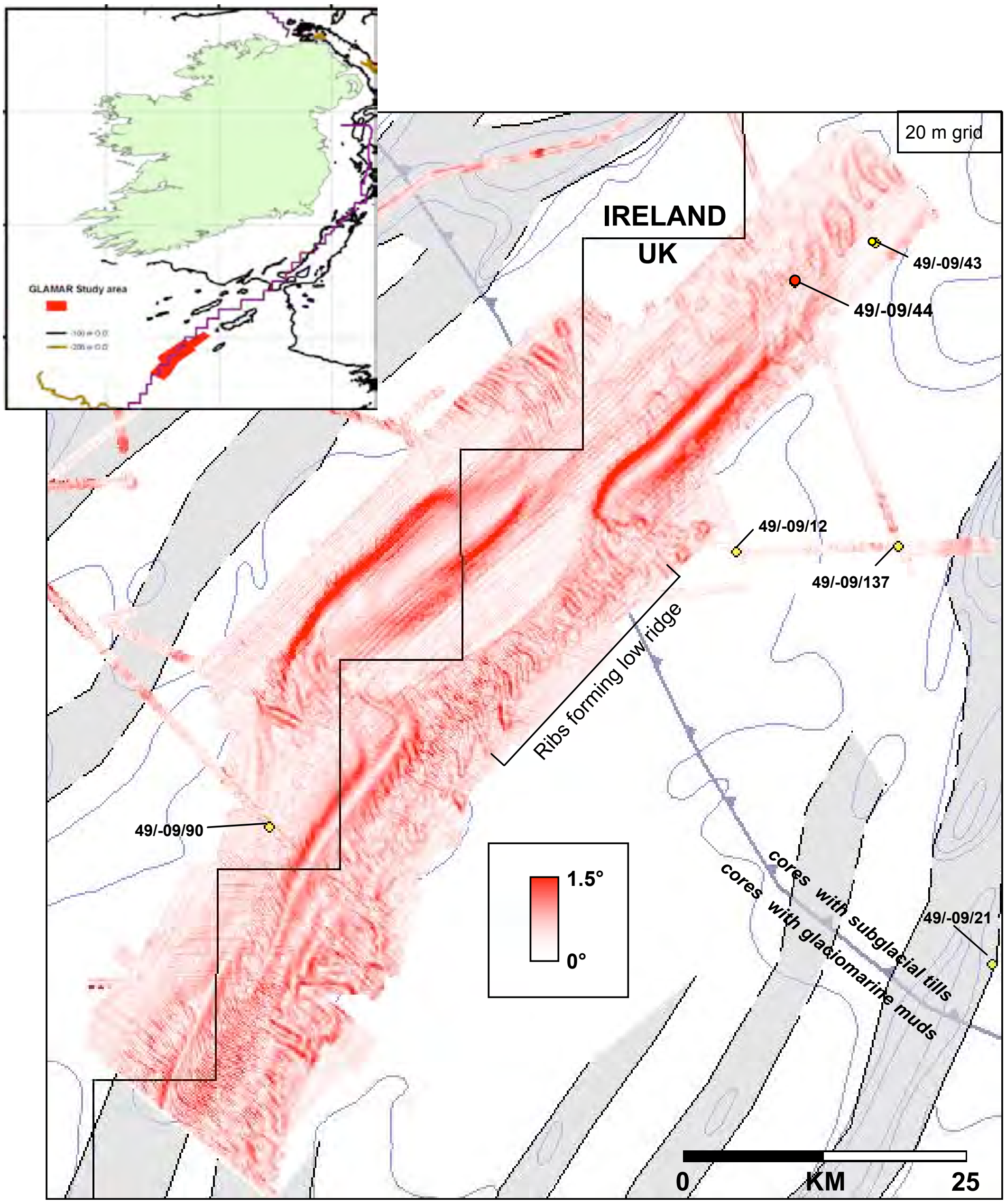


***Figure 12** – Slope map of GLAMAR multibeam mosaic at a 20 m grid (cf. Fig. 2).*

cross-sectional forms (e.g. Fig. 14b, 15b), as well as variable spacing due to frequent plan-form intersections. Smaller ridges (3-7 m high, up to 400 m wide) have more regular plan-forms and spacings, with cross-sections that may display a consistent asymmetry (Fig. 15a). The two types of ribs occur together and give way laterally to each other (Fig. 15), so that in places the distinction is subjective. The slopes of both feature do not exceed 1.5°, steeper slopes occur both on their seaward (SW) and landward (NE) faces (Fig. 12).

From profile data, Pantin & Evans (1984) noted that ridges in the UK and eastern Irish sector

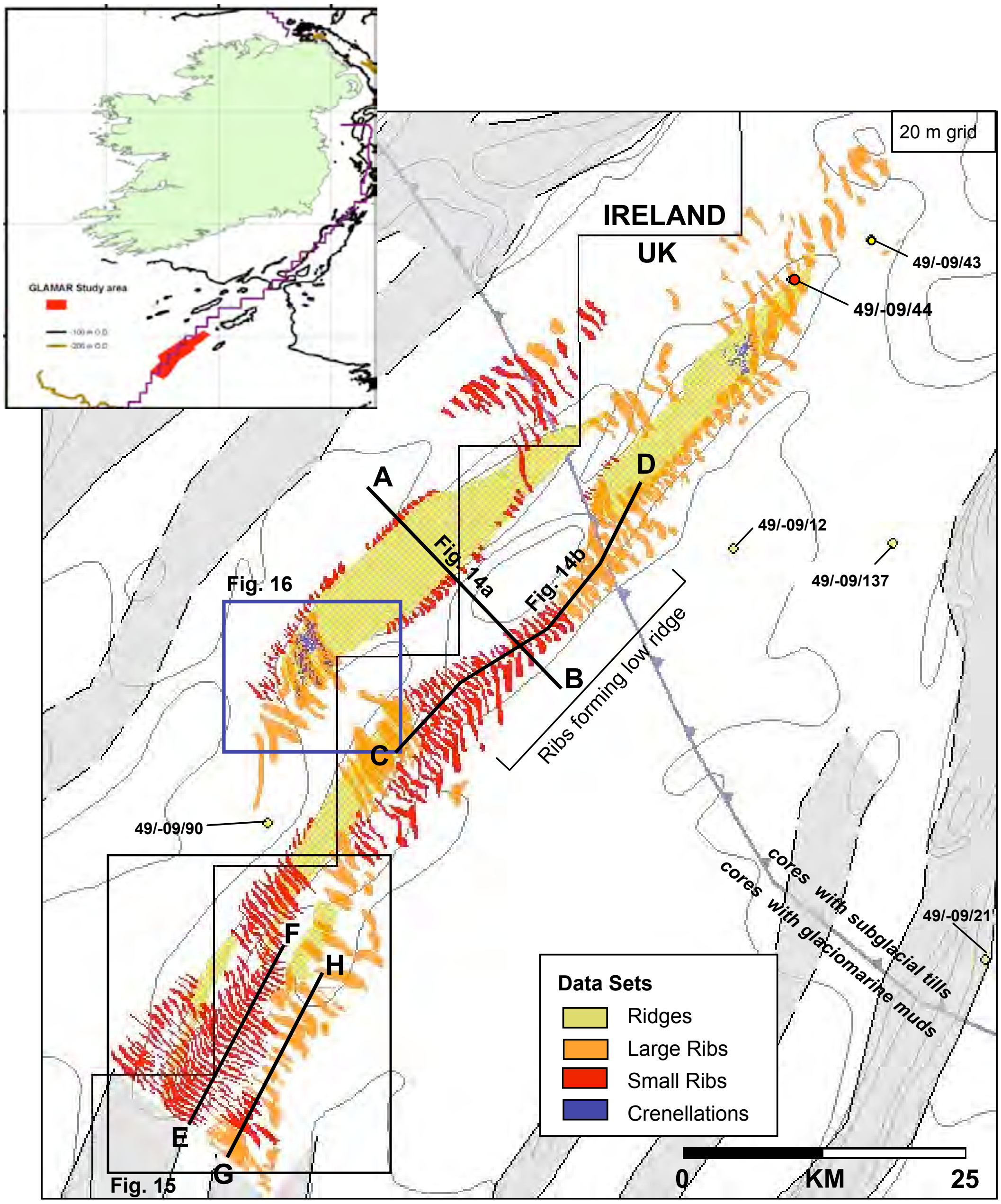


Figure 13 *– Interpreted morphological features within the GLAMAR multibeam mosaic (cf. Fig. 11).*

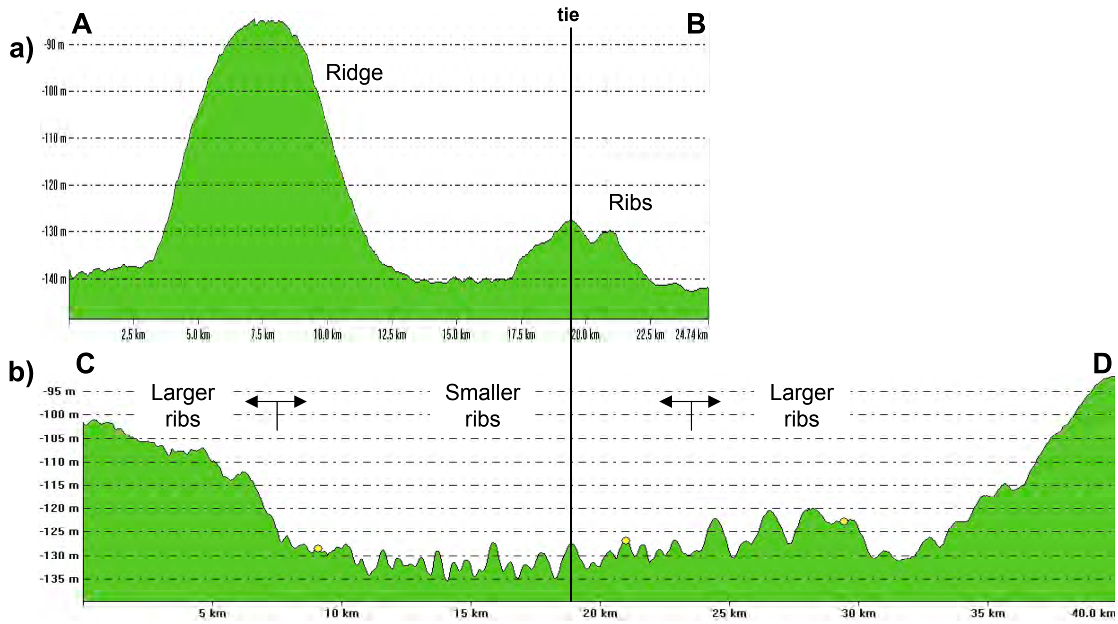


Figure 14 *–Profiles across (top) and along (bottom) a train of transverse ribs forming a low ridge; the ribs include both larger and smaller forms (see Fig. 13 for morphotypes and locations).*

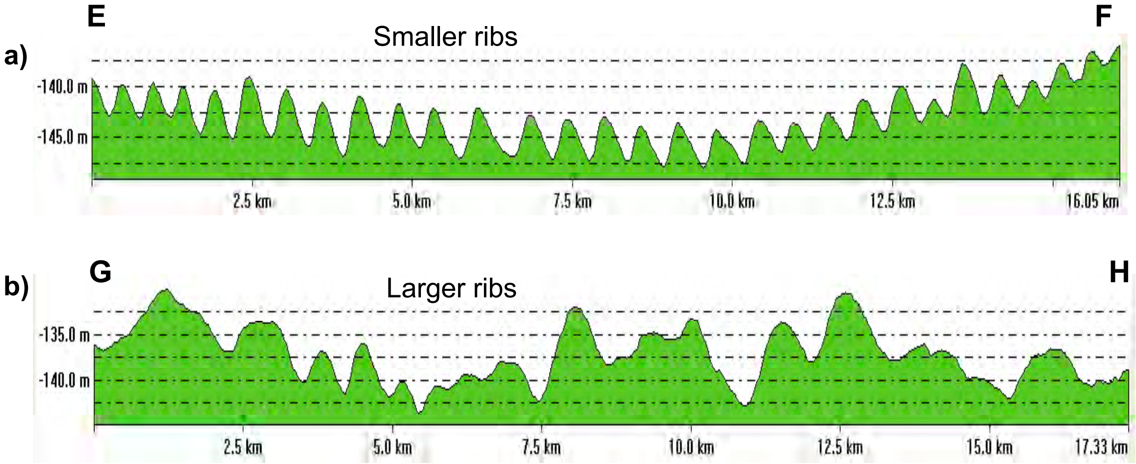
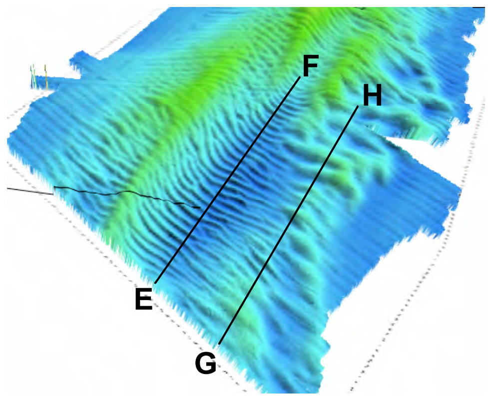


Figure 15 *–Details of two types of transverse ribs observed in the study area, smaller (a) and larger (b), which give way laterally to each other (locations also in Fig. 13).*



varied from larger features with smooth cross-profiles to "highly irregular forms with several separated high points", typically of lower relief; the latter appear to correspond to the ribs identified here. Similar highly irregular ridges of low relief were noted to occur in the French sector (Bouysse et al. 1976). The latter authors used profile data to describe ‘ridens’ or sand waves (up to 20 m high, 500 m spacing), which occur both on the flanks of the main ridges and seaward of them in a broad area on the outermost shelf (zone de l’Esperance) where they are estimated to be 4-5 km long (Bouysse et al. 1976). A similar broad area of shelf-edge ridens, described as large sand waves (up to 12 m high, average spacing 850 m), had been reported farther east in the La Chapelle Bank, in ‘trains’ oriented parallel to the shelf edge and transverse to the axes of the ridges to the north (Cartwright & Stride 1958; Carruthers 1963).

Comparable features have been previously observed on multibeam data acquired across the Kaiser-i-Hind Bank in the French sector, which is flanked by transverse to oblique bedforms, including larger features (up to 8 m high, several kilometers long) of varying orientation, and much smaller features (of more regular orientation and spacing, generally <10 m) that are in places are superimposed (Reynaud et al. 1999a). The bedforms are both interpreted as tidal dunes, but it is noted that the height to length ratio of the larger features is anomalous, while their range of orientations would imply various current orientations (Reynaud et al. 1999a).

In summary, the transverse ribs observed in the GLAMAR dataset appear to represent features that occur elsewhere in the Celtic Sea, on the flanks of seabed ridges and seaward of them on the shelf edge. They have been interpreted as large sand waves, and subsequently cited as being among the largest such features in the world (Off 1963).

4.2.3 Crenellations

This term was used by Pantin & Evans (1984) to refer to small-scale (<2 m) relief observed on pinger profiles from the Celtic Sea ridges and inter-ridge areas, in which “some… tend to rise above the general level, whereas others … mainly fall below”. This description applies well to features observed on the GLAMAR multibeam data, for which it is generally uncertain if they are positive or negative features. The crenellations are of remarkably low relief (mainly ≤1 m), with wavelengths of 80-200 m and variable orientations that are difficult to map in detail. The complex morphology of the crenellations has been mapped in two areas of interest (see Fig. 13).

Details of one area are shown in Figs 16 & 17. The crenellations in this area are seen to be superimposed on and intimately associated with the transverse ribs that extend across this part of the ridge (Fig. 16). Crenellations are broadly oriented parallel to the ribs, prominent on their crests, but also present in intervening depressions. The pattern of the features is clear, although it is difficult to known whether they are low furrows or ridges. In one part of the area, two of the features are seen to be broad trenches that narrow to the NW, although they are flanked by low ridges (Fig. 17).

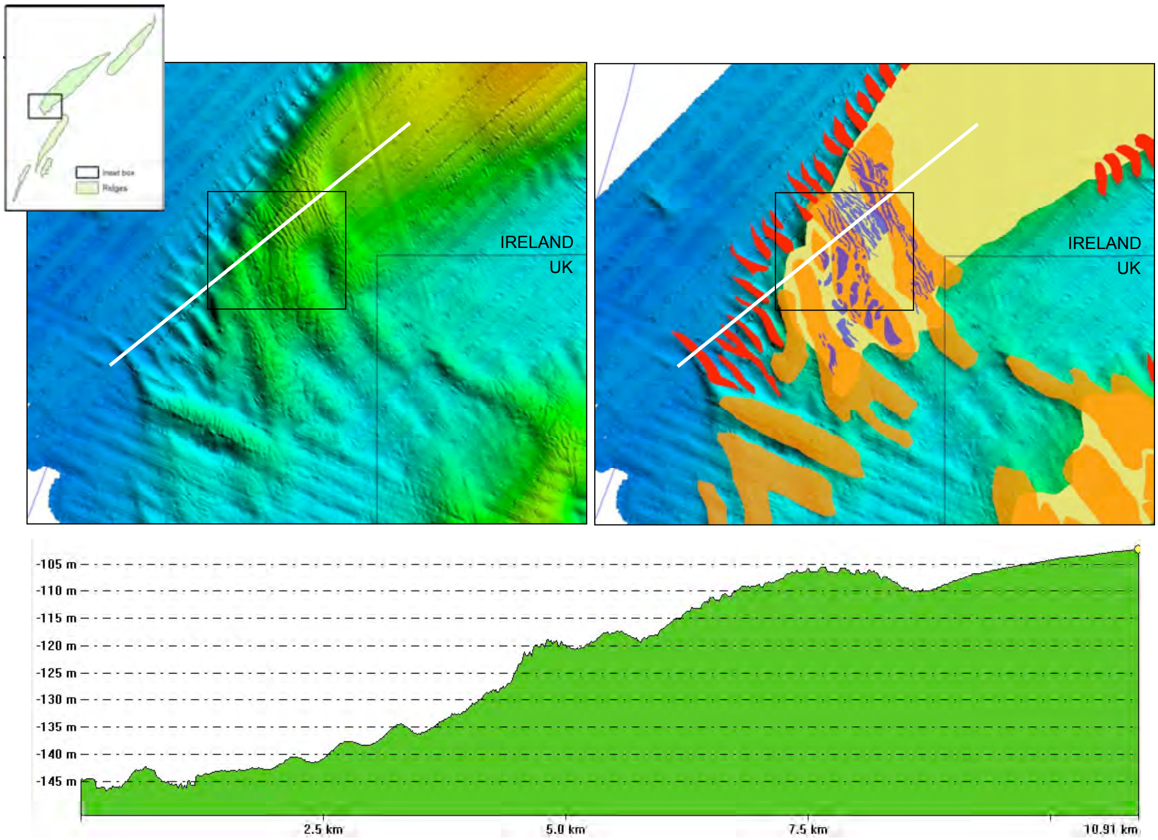


Figure 16 *–Details of crenellations in the Irish sector (see Fig. 8 for location).*

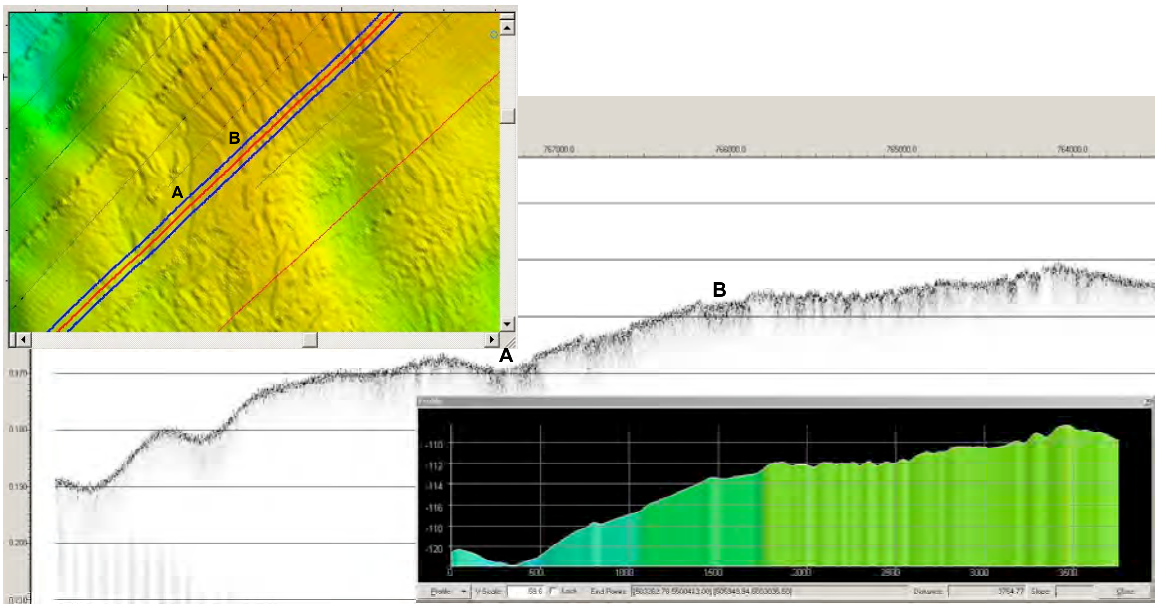


Figure 17 *–Chirp subbottom profile across crenellations in the Irish sector (area shown in Fig. 14). The crenellations are seen to include two broad trenches (A & B), flanked by small elevations. Elsewhere it is not clear if the crenellations are positive or negative features.*

Pantin & Evans (1984) suggested that the crenellations they observed might correspond to the isolated mounds of till-like material observed, separately, on sidescan sonar imagery. The multibeam data shows that the crenellations do not correspond to mounds (Figs 16, 17), nor is there an obvious correlation to gravelly seabed sediments (see Fig. 5). The crenellations are similar in size and form to low relief linear features observed on the flanks of glacial banks on the Norwegian shelf, which have been interpreted as 'rippled scour depressions' formed by bottom currents (Bellec et al. 2010). However, this interpretation is open to question, as some of the features on the Norwegian shelf are noted to be the extension of furrows developed higher on the banks (Bellec et al. 2010), whereas rippled scour depressions elsewhere appear to be depositional features developed within mobile sand sheets (e.g. Goff et al. 2005).

5. STRATIGRAPHIC ANALYSES

BGS seabed mapping of the Irish-UK Celtic Sea resulted in a regional stratigraphic framework, within which the relation of the seabed ridges to glacigenic sediments remains ambiguous. Analyses of the GLAMAR sparker and Chirp profile data are still ongoing, but have allowed identification of the main stratigraphic units and an initial correlation of sediments overlying the ridges to glacigenic units in five BGS vibrocores.

5.1 BGS Regional Framework

The stratigraphic framework for the Irish-UK sectors of the Celtic Sea that emerged from BGS mapping of the mid- to outer shelf is summarized in Fig. 18. The framework is based on the integrations of seismic stratigraphic units with cored sediments.

Seabed sediment Layers A & B (<1-2 m thick) are underlain by two main units, the Melville Formation (forming the bulk of the seabed ridges) and the Little Sole Formation, which truncate a succession of seaward-dipping Neogene and older sedimentary strata (Pantin & Evans 1984; Evans 1990). The Little Sole Fm is informally divided into two units, the upper extending across the outer shelf beneath the Melville Fm. A single sample has been attributed to the upper Little Sole Fm, of early Pleistocene glauconitic muddy sand. Elsewhere, areas underlain by the Melville and/or upper Little Sole Fms have yielded cores in which Layers A and B are underlain by coarse-grained sediments that cannot be distinguished, referred to as Layer C (predominantly bedded sands including gravel or shell beds and occasional muddy layers).

The upper Little Sole Formation is up to 50 m thick and rests on an irregular basal reflector that includes channels (Pantin & Evans 1984); it was not possible to map the channels across the outer shelf, in contrast to the French sector where broader channels, some overdeepened, occur beneath and subjacent to the ridges and many can be traced to the shelf edge (e.g. Bouysse et al. 1976; Reynaud et al. 1999, 2003). The upper Little Sole Formation is separated from the overlying Melville Formation by a generally strong, often flattish reflector that merges with the near-seabed unconformity between the ridges. Both formations show “a considerable amount of internal structure”, mainly in the form of cross-bedding, consistent with predominantly sandy characters. The Melville Formation varies from 60 m thick in the ridges to <5 m between them.

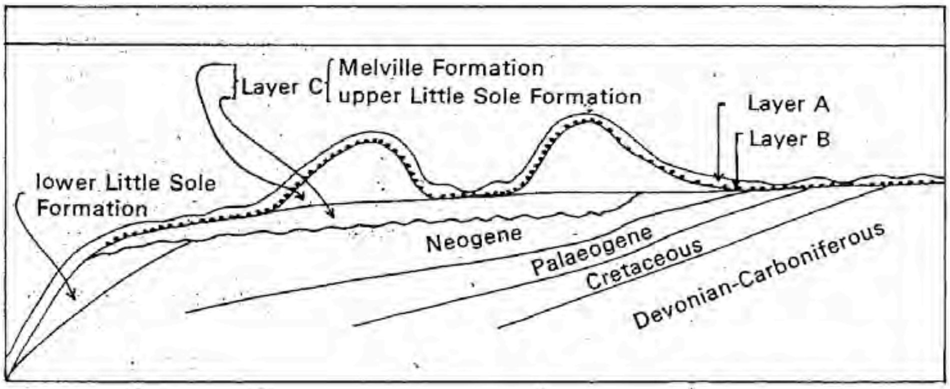


***Figure 18** – Schematic stratigraphy of the mid- to outer shelf of the Irish-UK Celtic Sea according to Pantin & Evans (1984). The Melville Formation includes the bulk of the sand ridges as well as glacigenic sediments proven in cores (Melville Till and Melville Laminated Clay – Scourse et al. 1990).*

Vibrocores which have reached Layer C on the seabed ridges are said to have encountered “clean, sporadically gravelly sand” (Evans 1990, p. 76). However, at a few locations “the normally sandy sediments of Layer C are either replaced by, or underlain by… till-like sediment” (Pantin & Evans 1984, p. 271). Uncertainty as to the stratigraphic relationship with the Layer C sands reflects the fact that most such samples come from inter-ridge areas, save one vibrocore (49/-09/44) located on the flank of a ridge (Fig. 2). In addition, the till-like sediments were interpreted as a discontinuous layer of probable ice-rafted material by Pantin & Evans (1984). However, Scourse et al. (1990) interpreted them as subglacial tills and glacimarine sediments, lithostratigraphically identified as the Melville Till and Melville Laminated Clay, both members of the Melville Formation. The stratigraphic relationship of the glacigenic sediments to the sandy sediments of the Melville Formation remains ambiguous, vibrocore 49/-09/44 providing the only evidence that the latter underlies the former.

5.2 GLAMAR Profile Data

The aim of RIDGES was to obtain an independent stratigraphic scheme through digital interpretation of the GLAMAR geophysical profiles and their correlation to five BGS vibrocores (see Fig. 19). It proved possible to make progress towards this goal via separate interpretations of the sparker and Chirp profiles, while learning useful lessons regarding the analysis of high resolution seismic data with a commercial software package.

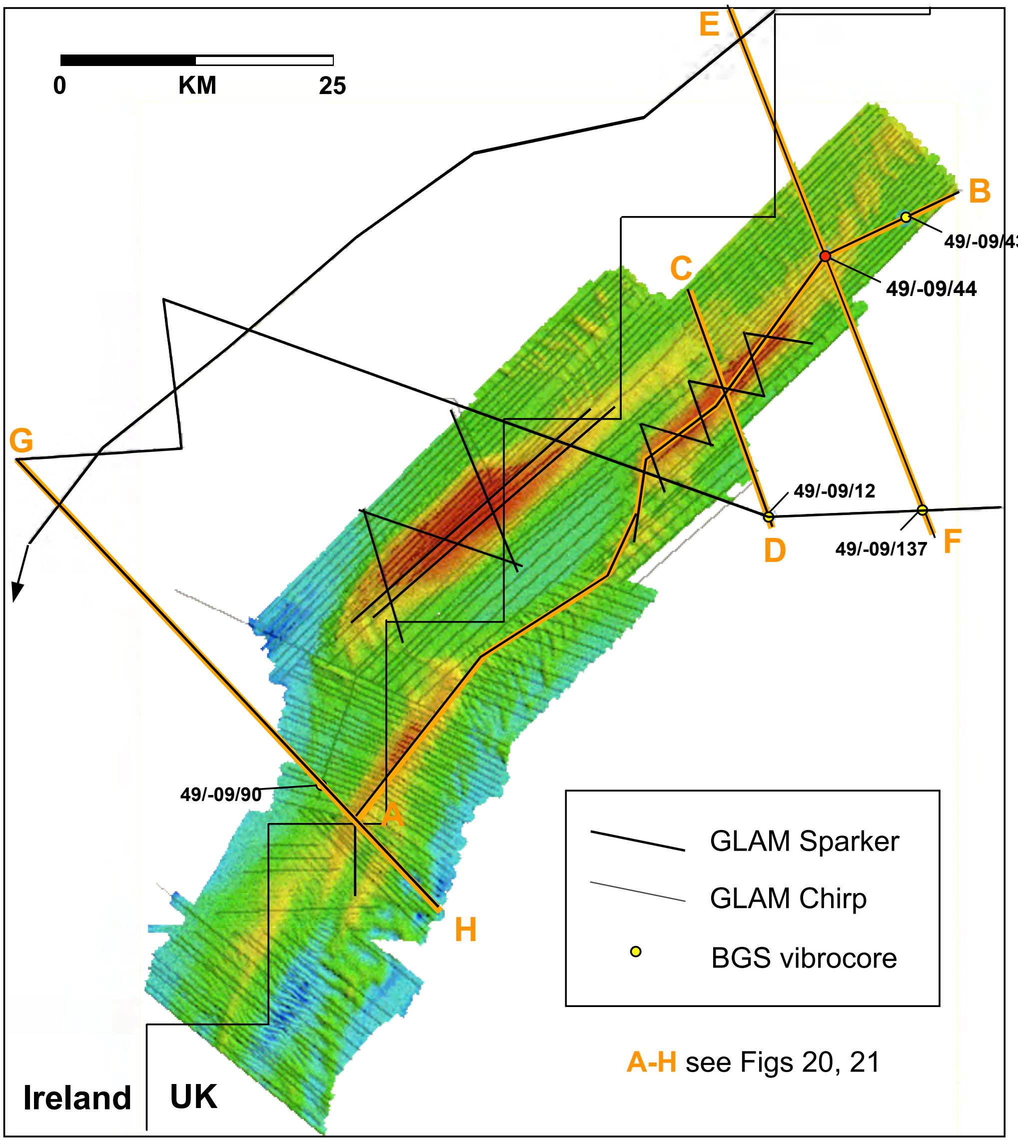


Figure 19 *– Distribution of GLAMAR sparker profiles (22) and Chirp profiles (140) loaded into SMT Kingdom Suite, along with BGS vibrocore locations.*

A set of 22 sparker profiles and 140 Chirp profiles (see Appendix D) was successfully loaded into SMT Kingdom Suite, along with the BGS vibrocore locations and a raster image of the multibeam DTM (see Fig. 19). Tracing of reflections across the grid of profiles was discovered to be complicated by several factors: i) uncorrected wave motion, which frustrates attempts at automatic picking (along with high-frequency content and noise content); ii) uncorrected tidal variations of up to 6 ms (4 m), which complicate tie-line correlations (and preclude the gridding of horizons to generate surface maps or isopachs); iii) the differing resolutions and reference levels of the sparker and Chirp data. These problems were exacerbated by the shallow water depths (80-150 m), which make the data more sensitive to small vertical variations, as well as to variations in data quality due to sea conditions during acquisition.

In addition, it proved expedient to interpret the sparker and Chirp profiles in separate Kingdom projects. This was problematic as the two data types provide complementary information: Chirp profiles provide up to 20 ms of subbottom penetration, greatest on the flanks of the ridges and in inter-ridge areas, where sediment thickness is typically less than the resolution of the sparker profiles (<5-10 ms). Integration of the two data types to obtain a unified stratigraphic framework is in progress, but it was not possible to complete in the time available for RIDGES.

However, it was possible to identify the main BGS stratigraphic units on the sparker profiles; and to trace a set of up to 5 reflections through the Chirp dataset that allow a preliminary correlation to these units and to glacigenic sediments in five BGS vibrocores, as outlined below.

5.2.1 Regional units (sparker profiles)

The main units identified during BGS mapping (cf. Fig. 18) are readily identified on the GLAMAR sparker profiles. Seaward dipping Oligo-Miocene strata (Jones Formation) are truncated by an unconformity that is overlain by two main units, recognized as the upper Little Sole Formation and the overlying Melville Formation, the latter forming the bulk of the seabed ridges (Figs 20, 21). In most inter-ridge areas, both formations thin to less than the practical resolution of the sparker system (<5-10 m).

The upper Little Sole Fm is discontinuous, of variable geometry and closely associated with the Melville Fm. In the south of the area, the upper Little Sole Fm is recognised beneath one ridge in axial profile (Fig. 20a), as an apparently tabular unit separated by a strong and not obviously discordant reflection from the overlying Melville Fm; in cross-section, however, the unit does not continue to either side of the ridge and appears to form part of it (Fig. 21b). In the north of the area, buried channels are observed subjacent to the ridges (Fig. 21a) and inferred to correspond to the upper Little Sole Fm (cf. Pantin & Evans 1984).

The Melville Formation forms the bulk of the seabed ridges and causes reflection pull-ups beneath them (e.g. Fig. 20), although not all reflection relief beneath the ridges can be attributed to pull-ups, as noted by Pantin & Evans (1984). Some relief is seen to be due to differential erosion of underlying strata and/or the presence of the upper Little Sole Fm (e.g. Fig. 21a&b).

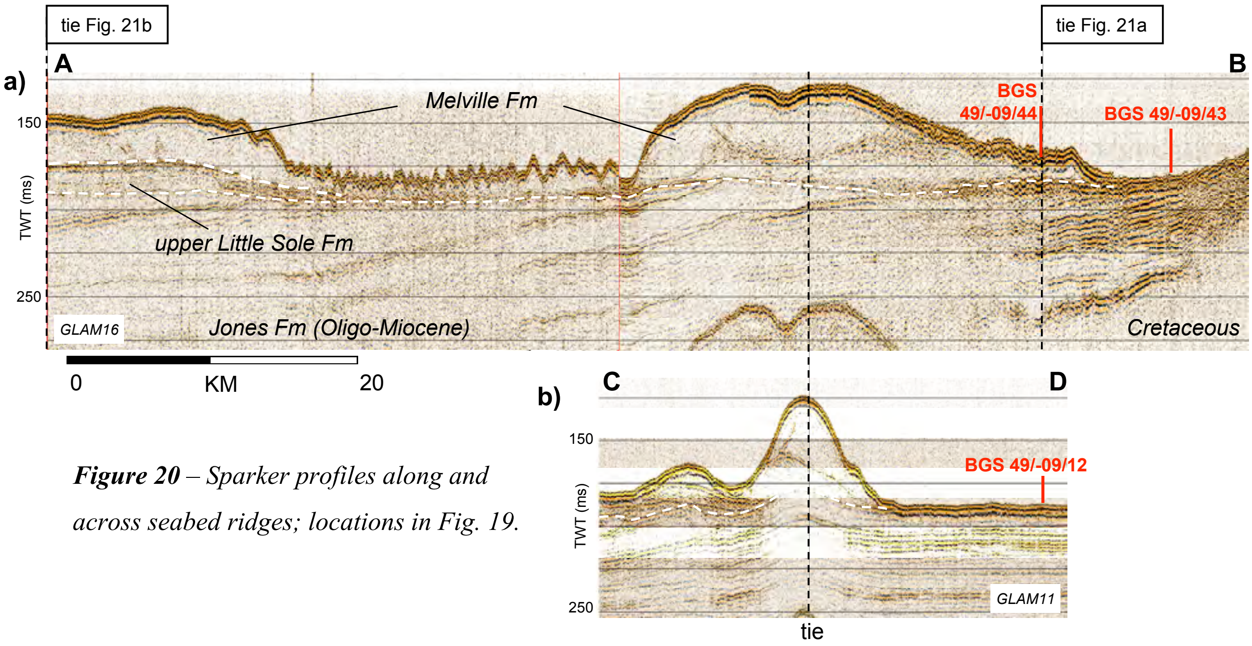


Figure 20 *– Sparker profiles along and across seabed ridges; locations in Fig. 19.*

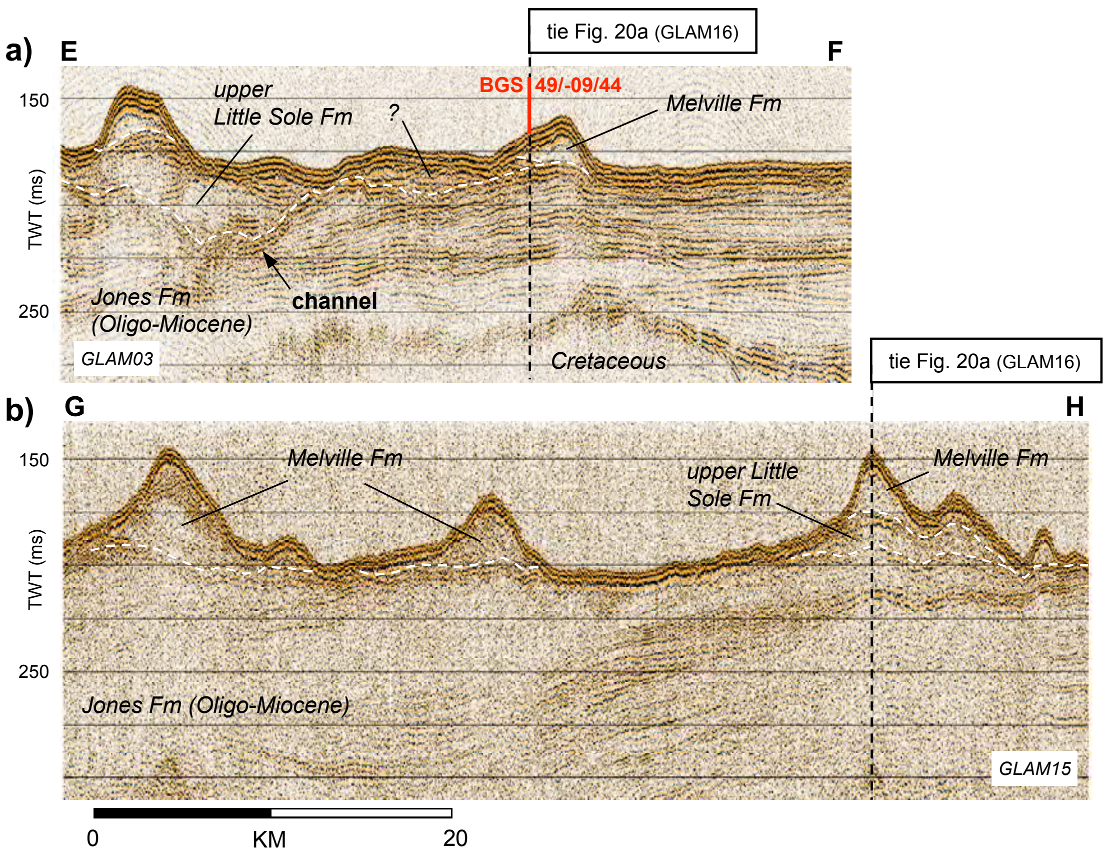


Figure 21 *– Sparker profiles across ridges in the GLAMAR study area, see Figs 20 & 21.*

Much of the Melville Fm lacks coherent reflections, but in places the ridges include clinoforms indicative of large-scale cross-bedding (Figs 20, 21); these characteristics have been reported from previous work in the Irish-UK sectors and used to infer a sandy character (Stride 1963a; Pantin & Evans 1984; Evans 1990). Axial profiles reveal reflections dipping in opposite directions, i.e. both seaward (SW) and landward (NE), although cross-profiles indicate a component of non-axial dip (Fig. 20); such stratal geometries are comparable to those observed in the Kaisir-i-Hind Bank in the French sector, where they have been shown to record axial growth (Marsset et al. 1999; Reynaud et al. 1999b).

The Melville Fm thins to less than the resolution of the sparker system (<5-10 ms) in most inter-ridge areas (Figs. 20, 21). Exceptions are the transverse ribs, which are seen to have a transparent or locally stratified seismic character like that of the ridges. In Fig. 20a, the train of transverse ribs joining two ridges is seen to be in physical continuity with the Melville Fm within the ridges, with no indication of an intervening reflection (nor is one observed on the Chirp profiles). Thus the ribs also seem to be part of the Melville Formation and possibly of similar composition to the ridges.

5.2.2 Ties to BGS vibrocores (Chirp profiles)

Chirp profiles reveal a series of strong reflections within the upper 20 ms sub-seabed that can be traced across much of the study area (see Figs 22-25); these reflections have yet to be transformed into stratigraphic units. However, as a first step, sub-metric scale resolution allows correlation of the reflections to glacigenic sediments within each of five BGS vibrocores within the study area, presented below (Figs 19, 22-25).

A series of up to 5 sub-seabed reflections was traced throughout the grid of 140 Chirp profiles loaded into SMT Kingdom Suite; this exercise also served to show that 29 of the profiles contained no useful subbottom information. The maximum number of reflections identified on the remaining 111 profiles are listed in Appendix D (which concludes with a map of those profiles that contain more than 3 reflections).

It is emphasized that the 5 reflections were not drawn as unit boundaries; although shown with differing colours in Figs 22-25, many may be interchangeable, in particular the upper three. Nonetheless, comparison of the reflections with those on the sparker profiles shows that in most cases the upper three (1-3) lie on or above the unconformity at the top of pre-Pleistocene strata, while the lower two correspond to underlying strata. Thus up to three units are recognized within the sediments overlying the regional unconformity.

Correlation of the reflections to five BGS vibrocores is shown in Figs 22-25 and summarized in Table 1. As noted previously, the vibrocores were positioned using the Decca Navigation System and their precise locations are open to question; differences between depths recorded on the field logs (using an unknown method) and those obtained from the GLAMAR DTM (Table 1) in some cases could imply positioning errors of up to a few kilometres. Nonetheless, at each site the depth to the first subbottom reflection on the Chirp profiles is found to be approximately consistent with the depth to the top of glacigenic sediments in the vibrocores; assuming an error of measurement of TWT of ± 0.5 ms, interval velocities are all in the range of 1.5-2.0 km/s typical of unconsolidated sediments (Table 1). These results may in part reflect the fact that the Chirp profiles generally show small changes in unit thicknesses over distances of a few kilometres (Figs 22-25). In any case, they support a first-order correspondence between the Chirp seismic stratigraphy and the vibrocore lithostratigraphy.

Table 1 – Correlation betweem BGS vibrocores and Chirp profiles

Vibrocore ID	Date	Sector	Field log** depth (m)	Multibeam depth - field log depth (m)	TD (m)	Glacigenic facies*	Depth to glacigenic (m)	Depth to 1st Refl. (ms)	Interval velocity (km/s)	Chirp profile(s)
49/-09/44	08/07/1978	UK	127	-6	5.40	A / B	2.0/5.0	5 ± 0.5	1.0 ± 0.5	CH52-55, CH170-173
49/-09/43	08/07/1978	UK	127	5	1.88	A	1.64	2 ± 0.5	1.6 ± 0.5	CH162-163, CH170-173
49/-09/12	16/07/1977	UK	151	-14	0.49	A	0.49	1 ± 0.5	1.0 ± 0.5	CH60-64, CH181-185
49/-09/137	13/08/1978	UK	118	14	1.51	A	1.51	2 ± 0.5	1.5 ± 0.5	CH56-58, CH60-64
49/-09/90	15/07/1978	Irish	137	3	1.55	B	1.2	1 ± 0.5	2.4 ± 0.5	CH209-212, CH336-337

**** A=Melville Till, B=Melville Laminated Clay (glacimarine) – Scourse et al. (1990, 1991)***
***** Information from field logs is summarized in Appendix B***

The longest vibrocore in the study area (and the Celtic Sea) is 49/-09/44, said to come from the flank of a ridge (Pantin & Evans 1984); its plotted position lies off the crest of a ridge, in an area where it appears to be breaking up into a train of larger ribs (cf. Figs 13, 22). The core penetrated c. 2m of sand and gravel and 3 m of glacimarine mud to bottom in 0.4 m of till (Fig. 22; Scourse and Furze 2001). Correlation to Chirp profiles suggests the till at 5 m depth to correspond to a strong reflection at the base of a layer of sediments that mantles the ridge. The strong reflection also forms the base of the seabed ribs, which are therefore composed mainly of glacimarine mud (3 m) overlain by sand and gravel (2 m); the base of the latter does not correspond to a reflection. Shifting the location of the core by 1 km in any direction would not change this result.

Comparison with the coincident axial sparker profile (A-B in Fig. 20) shows that the sediments at the vibrocore site overlie the ridge. Thus these results confirm that the ridge at site 49/-09/44 is overlain by glacial till, which is seen to form of the base of transverse ribs that are composed in large part (3/5 m) of glacimarine mud (3/5 m) overlain by sand and gravel. This finding suggests that the seabed ribs are plausible glacigenic bedforms.

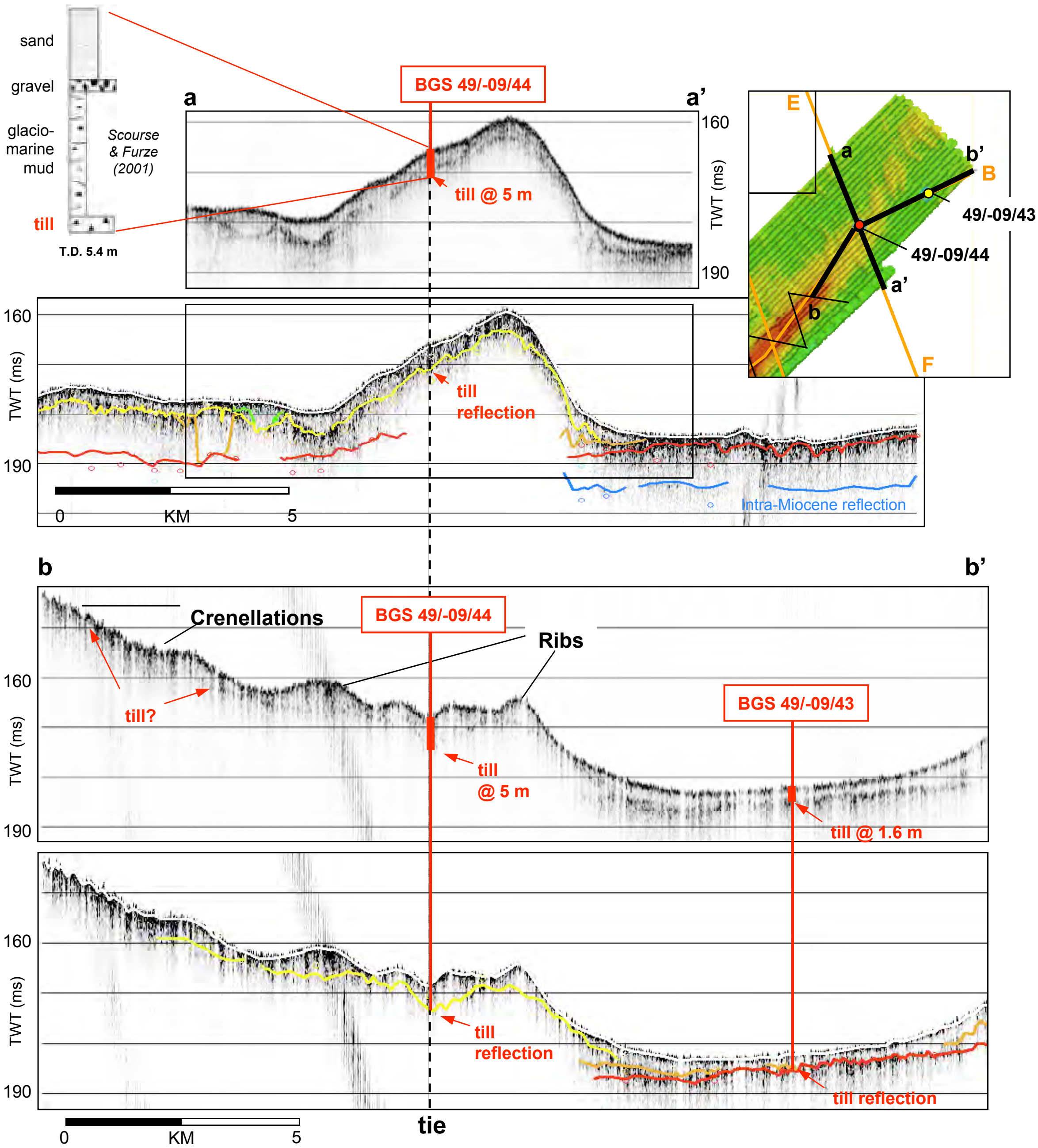


Figure 22 – Correlation of BGS vibrocores 49/-09/43 & 44 to reflections observed on Chirp profiles. The profiles are coincident with sparker profiles A-B and E-F (Figs 19-21). Seabed ribs are seen to be composed in part of glacimarine mud overlying glacial till.

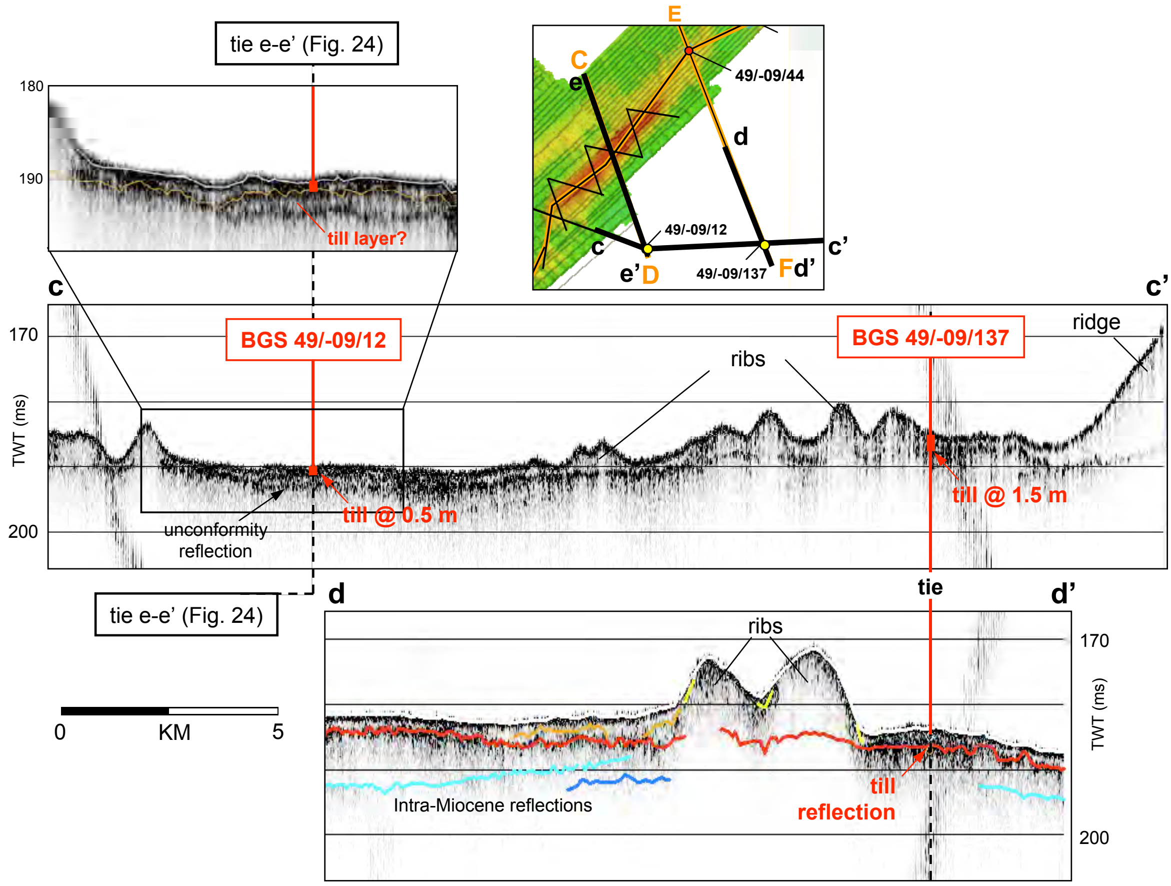


Figure 23 – *Correlation of BGS vibrocores 49/-09/12 & 137 to reflections observed on Chirp profiles. Profile d-d' is coincident with sparker profile C-D (Fig. 20), profile e-e' is shown in Fig. 24.*

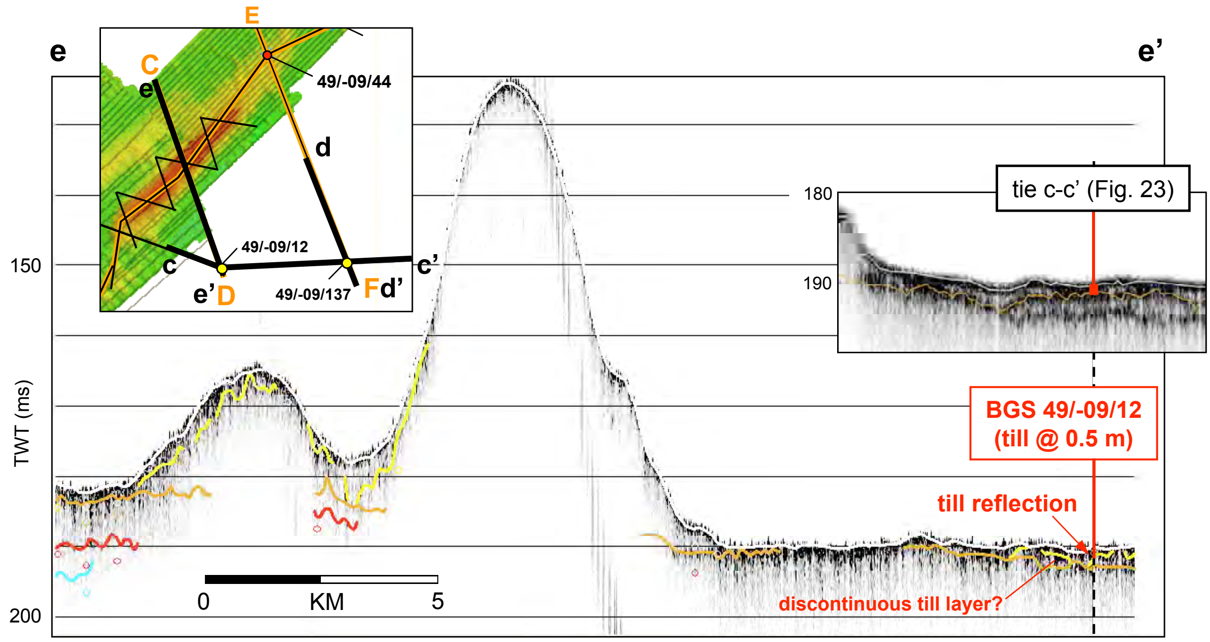


Figure 24 – *Correlation of BGS vibrocore 49/-09/12 to reflections observed on Chirp profiles. Profile e-e' crosses c-c' (Fig. 23).*

The site of vibrocore 49/-09/44 lies 7.9 km from that of vibrocore 49/-09/43 (Fig. 22), which proved 1.6 m of sand over 0.24 of till (Scourse & Furze 2001; Appendix B); the depth of the till corresponds to a strong reflection on the Chirp profile (Fig. 22, Table 1). The strong reflection in this area is seen to define the top of a discontinuous sediment layer, up to 1 ms (c. 1 m) thick, that overlies a second reflection inferred to correspond to the angular unconformity on Miocene strata (Fig. 22). Assuming the vibrocore is within a few kilometres of its reported position, the discontinuous sediment layer could therefore correspond to glacial till. The field log depth of this vibrocore is the same as that of 49/-09/44, which however lies 11 m higher on the GLAMAR data (e.g. Fig. 22).

Some 25 km to the south, vibrocores 49/-09/12 & 137 also proved till beneath sands, at depths (0.5 m and 1.5 m respectively) that correspond to a strong reflection on the Chirp profiles (Fig. 23). At site 49/-09/137 the strong reflection appears to correspond to the angular unconformity. At site 49/-09/12, it corresponds to the top of a sediment layer up to 2 ms (c. 2 m) thick, which again could correspond to a discontinuous layer of glacial till. The field log depths of both vibrocores differ by 14 m from the multibeam depths (Table 1); this could only be accommodated by positioning errors of >5 km, so the field log depths may be in error.

Vibrocore 49/-09/90 lies some 50 km to the SW in the Irish sector and bottomed in 0.35 m of glacimarine mud, beneath 1.2 m of sand and gravel (Scourse et al. 1990; Scourse & Furze 2001; Appendix B). The depth of the glacimarine mud corresponds to a reflection at the top of an interval that appears to form part of the seabed ridge and which includes smaller transverse ribs on the flanks of the ridge (Fig. 25).

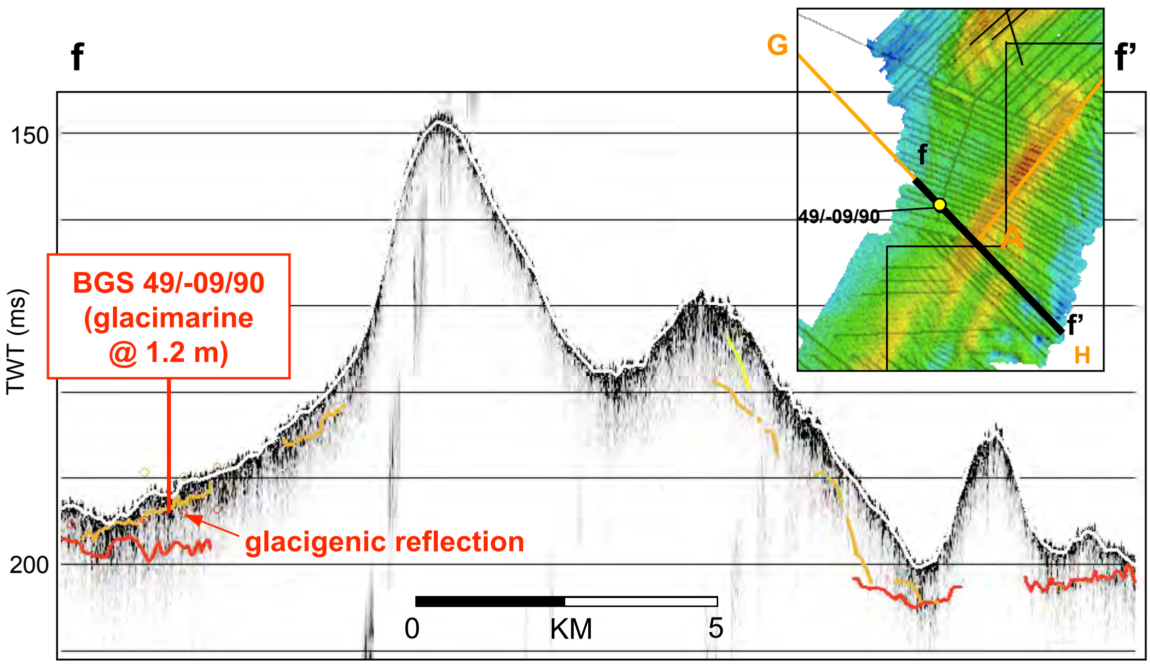


***Figure 25** – Correlation of BGS vibrocores 49/-09/12 & 137 to reflections observed on Chirp profiles. Profile d-d' is coincident with sparker profile C-D (Fig. 20). Profile e-e' is shown in Fig. 24.*

6. OUTCOMES AND FUTURE WORK

The activities undertaken during RIDGES, presented above, have yielded outcomes at two scales, that of the Irish-UK sector as a whole and that of the mid- to outer shelf GLAMAR dataset. These may be summarised as follows:

- the identification of legacy seismic and sample datasets providing information on the seabed of the Irish-UK sectors, including parts of the Irish sector;
- the identification of new ridges in the Irish sector, which is also seen to include the longest, broadest and least explored part of the ridge system in the Celtic Sea;
- the mapping of remarkable transverse bedforms (ribs, crenellations) across the ridges in the GLAMAR study area, which extend continuously across the postulated limit of glaciation and are inferred to include features present throughout the Celtic Sea, previously interpreted as marine bedforms;
- stratigraphic correlation of GLAMAR sparker and Chirp profiles to the existing regional framework and to glacigenic sediments in BGS vibrocores, confirming the ridges to be overlain by glacial till and suggesting the ribs to be subglacial bedforms.

The provisional identification of the transverse ribs as subglacial bedforms is of particular interest, as these extend across and at least 65 km beyond the currently accepted limit of glaciation in the Celtic Sea (Figs 1, 2). Analyses of the GLAMAR dataset yield no evidence for an ice margin across the study area, so a general result of RIDGES is that the seaward extent of the Celtic Sea sector of the last British-Irish Ice Sheet remains open to question. The results above provide support for the hypothesized glacial (glaciofluvial) origin of the Celtic Sea ridges, with broad implications for reconstructions of the extent and dynamics of the Irish Sea Ice Stream and for our understanding of the delivery of meltwater and sediment to the continental slope during the last glaciation.

These results are also relevant to future investigations of both the Irish and UK sectors of the Celtic Sea, by raising basic questions as to the origin of seabed features and the nature of sediments at seabed. In particular, they suggest the following perspectives on the formulation of research agendas for future phases of seabed mapping:

- submarine geomorphology: it is of interest to acquire more swath bathymetric data from the ridges and inter-ridge areas, to determine the seaward extent of the transverse ribs identified during RIDGES, in particular their seaward extent towards the shelf edge;
- stratigraphy: the nature and relations of the stratigraphic units over- and under-lying the seabed ridges require ground-truthing, through the targeted acquisition of vibrocores from key sites where multiple sub-bottom reflections are identified on geophysical profiles;

- seabed sediments: the presence of a till-like material at seabed raises questions about the possibly widespread occurrence of hard grounds in an area thought to be predominately blanketed in shifting sands; sampling and/or video imagery of such targets could confirm or reject the hypothesised link to crenellation-dominated seabed morphology.

These perspectives are of direct relevance to future investigations of the Irish Celtic Sea in the context of INFOMAR's mission of mapping Ireland's offshore territories. They suggest a research agenda that is currently being anticipated by the GLAMAR/RIDGES consortium through ship-time proposals.

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ANNEX 1 – DISSEMINATION ACTIVITIES

RIDGES was announced as a New Research Project in the March 2010 IQUA Newsletter. Interim results from the project were presented as talks and posters throughout the project period at seven international and national meetings, listed below.

IQUA Newsletter

Praeg, D., McCarron, S., Stoker, M. (2010). RIDGES: Investigating glacial landscapes in the Irish-UK Celtic Sea. *IQUA Newsletter*, no. 44, March 2010, p. 8-9.

Oral and poster presentations at conferences

1. Praeg, D. & the OGS Explora Scientific Party (2009). A subglacial meltwater drainage pathway across the Celtic Sea continental shelf? First results from the IPY GLAMAR campaign [*oral*]. *Glaciogenic Reservoirs and Hydrocarbon Systems*, Geological Society, London, 1-2 December 2009; *Abstracts*, p. 55.
2. Praeg, D., McCarron, S., Stoker, M. & the GLAMAR Shipboard Party [*A. Cova, D. Accettella, A. Caburlotto, L. Facchin, L. Sormani, I. Tonini, G. Visnovic*] (2010). GLAMARous RIDGES : new data on the glaciation of the Celtic Sea [*oral*]. IGRM2010, 53rd Irish Geological Research Meeting, Ulster Museum, Belfast, 19-21 February; *Programme and Abstracts*, p. 33.
3. Praeg, D., McCarron, S., Stoker, M. & the GLAMAR Shipboard Party (2010). GLAcial Meltwater and the Continental MARgin of NW Europe: initial results from the IPY GLAMAR campaign to the Irish-UK Celtic Sea [*poster*]. IPY-OSC: International Polar Year, Oslo Science Conference, 8-12 June 2010 (http://ipy-osc.no/abstract/385625).
4. Praeg, D. et al. (2010). Above IPY poster presented at a 1-day workshop at the Geological Survey of Ireland, Dublin, on 11 June (organized by X. Monteys).
5. Praeg, D., McCarron, S., Stoker, M., the GLAMAR Shipboard Party [*Cova, A., Accettella, D., Caburlotto, A., Facchin, L., McManus, O., Sormani, L., Tonini, I., Visnovic, G.*] & Onshore Support Team [*Furey, T., Monteys, X., Verbruggen, K., Kenyon, N., Cotterle, D., Diviacco, P.*] (2010). GLAcial Meltwater and the Continental MARgin of NW Europe: initial results from the IPY GLAMAR campaign to the Irish-UK Celtic Sea [*poster*]. Atlantic Ireland 2010, 2 November, Burlington Hotel, Dublin, IRELAND; Abstracts Volume, pp. 57-58 (http://www.pip.ie/page/323).
6. Praeg, D., McCarron, S., Goldsberry, P., Stoker, M., the GLAMAR Shipboard Party [*Cova, A., Accettella, D., Caburlotto, A., Facchin, L., McManus, O., Sormani, L., Tonini, I., Visnovic, G.*] & Onshore Support Team [*Furey, T., Monteys, X., Verbruggen, K., Kenyon, N., Cotterle, D.*] (2010). GLAMARous RIDGES : new evidence on the glaciation of the Celtic Sea [*oral*]. Geoscience 2010, 3-4 November, Dublin Castle, IRELAND; Abstracts, p. 28 (http://www.gsi.ie/Geoscience+Initiatives/Geoscience+2010+Conference.htm).
7. Praeg, D., McCarron, S., Goldsberry, P., Stoker, M., the GLAMAR Shipboard Party [*Cova, A., Accettella, D., Caburlotto, A., Facchin, L., McManus, O., Sormani, L., Tonini, I., Visnovic, G.*] & Onshore Support Team [*Furey, T., Monteys, X., Verbruggen, K., Kenyon, N., Cotterle, D.*] (2010). GLAMARous RIDGES : exploring glacial landscapes in the Celtic Sea [*oral*]. IQUA Autumn Symposium, 26 November, Geological Survey of Ireland, Dublin, IRELAND; Abstracts (http://www.iqua.ie/Meet/Met_Hme.htm).

ANNEX 2 – SPIN-OFFS

RIDGES was associated with three main spin-off activities:

Training for research assistant

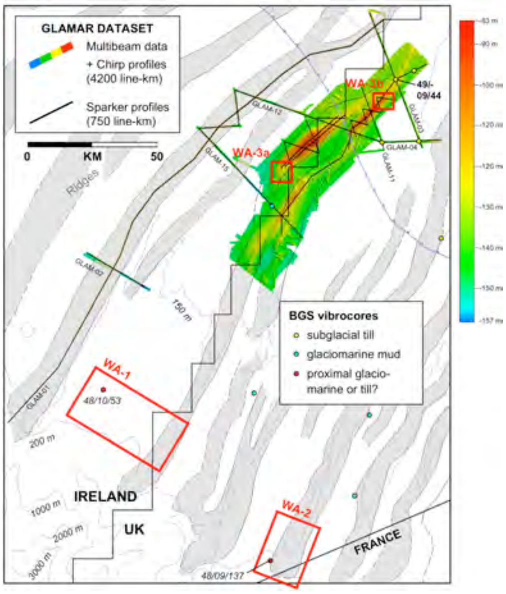
A research assistant, Paul Goldsberry, was recruited from UCD and worked at NUIM on the project for 4 months, from April to June and in August-September 2010. He received training in the use of marine geophysical data, including: a) management and visualization of offshore data using GIS systems, b) morphological analyses of seabed features, c) stratigraphic interpretation of high-resolution subbottom profiles (on a seismic workstation). Training activities included a 1 week visit to OGS in Trieste. He also took part in an INFOMAR oceanographic campaign.

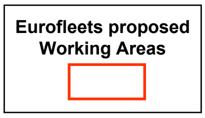
Ship-time applications

Applications were submitted to Eurofleets and INFOMAR for research cruises to the Celtic Sea:

a) *SW-ICE : SW Extent of the Last Ice Sheet on the European Atlantic Margin*

In response to a call for ship-time applications from the EC Eurofleets project (http://www.eurofleets.eu/), a proposal was submitted on 31 May 2010 for a Regional class vessel (1st choice Dom Carlos I, Portugal; 2nd choice Celtic Voyager, Ireland) to acquire additional seabed data from the Celtic Sea ridge system (EUROFLEETS-1025-021). Partners were OGS, NUIM and BGS (PI D. Praeg, OGS). The proposal was not rated for ship-time in 2011, mainly due to the lack of a French partner, and will be resubmitted for a follow-on call scheduled for February 2012.





b) *GATEWAYS I & II (2011 & 2012)*

In response to the INFOMAR call for ship-time applications for 2011 and 2012 (deadline 01 October 2010), a proposal has been submitted to investigate 'palaeo-ice streams on the SW Irish margin'. Partners are NUIM, OGS, Trinity College Dublin and the University Ulster (PI S. McCarron). The objectives are complementary to those of SW-ICE.

Network consolidation

The RIDGES project furthered the consolidation of an emerging international network of researchers with interests in the glacial history of the Celtic Sea, from Ireland (NUIM, UCD, GSI, Marine Institute), Italy (OGS) and the UK (BGS). Resubmission of the above Eurofleets application is expected to extend this network to French partners. The results from RIDGES are meant to inform a parallel Italian project, IPY GLAMAR, provisionally approved by the Italian polar funding body PNRA, which includes the above partners and researchers from the Geological Survey of Canada.

APPENDICES A-D

APPENDIX A – LISTING OF SAMPLE STATIONS (BGS)

Metadata listing of 150 BGS sample stations on the mid- to outer shelf of the Irish-UK sectors of the Celtic Sea, across the GLAMAR/RIDGES area of interest (see box in Fig. 6).

DGSQ	NUM	WHEN	LAT	LON	TD (m)	GS	VC	Sector	Comment
GS = Shipek grab *VC = vibrocorer*									
Vibrocores containing suspected glacigenic sediments (Scourse et al. 1990)									
+48-09	3	03/08/1978	48.82267	-8.48300	2.70	1	1	UK	glaciomarine
+48-09	137	27/07/1979	48.32500	-8.99333	1.53	1	1	UK	proximal glaciomarine or till?
+48-09	148	28/07/1979	48.54933	-8.56333	0.89	1	1	UK	glaciomarine
+48-10	51	28/08/1978	48.95750	-9.28500	1.34	1	1	UK	Upper Little Sole Fm (early Pliocene)?
+48-10	53	28/08/1978	48.90650	-9.86200	2.27	1	1	Irish	proximal glaciomarine or till?
+48-10	93	30/08/1978	48.89783	-9.07467	1.56	1	1	UK	glaciomarine
+49-09	12	16/07/1977	49.75000	-8.41167	0.49	1	1	UK	till (within GLAMAR dataset)
+49-09	21	30/07/1977	49.42083	-8.10583	1.14	1	1	UK	till
+49-09	43	08/07/1978	49.99400	-8.23750	1.88	0	1	UK	till (within GLAMAR dataset)
+49-09	44	08/07/1978	49.96333	-8.33733	5.40	1	1	UK	till (within GLAMAR dataset)
+49-09	90	15/07/1978	49.53333	-8.98417	1.55	1	1	Irish	glaciomarine (within GLAMAR dataset)
+49-09	137	12/08/1978	49.75350	-8.21350	1.51	1	1	UK	till (within GLAMAR dataset)
									Total 12
Stations within GLAMAR data coverage									
+48-11	4	04/08/1978	48.90417	-10.26417	2.80	1	1	Irish	nex to GLAM01 (on BGS 1978/4-55)
+48-11	5	04/08/1978	48.93667	-10.16367	1.50	1	1	Irish	on GLAM01 sparker line
+48-11	6	05/08/1978	48.84833	-10.04800	3.70	1	1	Irish	nex to GLAM01 (on BGS 1978/4-25)
+49-09	4	14/07/1977	49.92333	-8.41667	0.77	1	1	UK	"
+49-09	5	15/07/1977	49.83250	-8.58667	0.84	1	1	UK	"
+49-09	8	15/07/1977	49.74833	-8.74667	1.85	1	1	UK	"
+49-09	9	15/07/1977	49.66833	-8.91333	1.49	1	1	Irish	"
+49-09	10	15/07/1977	49.58250	-8.74167	1.85	1	1	UK	"
+49-09	11	15/07/1977	49.66167	-8.58000	1.42	1	1	UK	"
+49-09	25	31/07/1977	49.49917	-8.76833	1.20	1	1	UK	"
+49-09	26	31/07/1977	49.35500	-8.93667	0.50	1	1	UK	"
+49-09	45	09/07/1978	49.90933	-8.53183	1.76	1	1	Irish	"
+49-09	46	09/07/1978	49.88100	-8.63133	1.15	1	1	Irish	"
+49-09	47	09/07/1978	49.85050	-8.73100	1.69	1	1	Irish	"
+49-09	48	09/07/1978	49.82483	-8.82350	1.52	1	1	Irish	"
+49-09	50	09/07/1978	49.65017	-8.99717	2.53	0	1	Irish	"
+49-09	73	14/07/1978	49.76033	-8.61967	0.43	1	1	UK	"
+49-09	74	14/07/1978	49.73483	-8.71100	1.68	1	1	UK	"
+49-09	75	14/07/1978	49.70717	-8.80483	3.10	1	1	Irish	"
+49-09	89	15/07/1978	49.67767	-8.90300	3.20	1	1	Irish	"
+49-09	91	15/07/1978	49.56150	-8.88800	1.20	1	1	UK	"
+49-09	96	15/07/1978	49.61800	-8.69533	2.09	4	1	UK	"
+49-09	97	16/07/1978	49.59067	-8.79483	3.10	0	1	UK	"

+49-09	**98**	18/07/1978	49.44367	-8.86900	1.10	1	1	UK	"
+49-09	**99**	18/07/1978	49.41583	-8.96717	4.26	1	1	UK	"
+49-09	**135**	12/08/1978	49.78933	-8.51833	2.19	1	1	UK	"
+49-10	**15**	17/07/1978	49.50233	-9.07483	0.76	1	1	Irish	"
+49-10	**93**	21/08/1978	49.38517	-9.05783	1.66	1	1	Irish	"
+49-10	**94**	21/08/1978	49.35733	-9.15300	2.21	1	1	Irish	"
+50-09	**26**	13/07/1977	50.16333	-8.38167	1.76	1	1	UK	on GLAM01 sparker line
+50-09	**27**	13/07/1977	50.11500	-8.37833	2.90	1	1	UK	next to GLAM02 sparker line
+50-09	**28**	13/07/1977	50.09167	-8.27083	1.38	1	1	UK	within MB mosaic
+50-09	**29**	13/07/1977	50.06333	-8.37667	1.15	1	1	UK	next to GLAM02 sparker line
+50-09	**30**	14/07/1977	50.01333	-8.34333	1.21	1	1	UK	"
+50-09	**31**	14/07/1977	50.01667	-8.27167	1.72	1	1	UK	"
+50-09	**32**	14/07/1977	50.02167	-8.17083	2.25	1	1	UK	"
+50-09	**64**	07/07/1978	50.17750	-8.47350	3.05	1	1	Irish	on GLAM02 sparker line
+50-09	**67**	08/07/1978	50.01183	-8.39650	2.30	1	1	UK	"
									Total 38
Irish sector adjacent to and seaward of GLAMAR data									
+48-10	**1**	05/08/1978	48.764170	-9.935670	2.10	1	1	Irish	SW of multibeam mosaic
+48-10	**2**	05/08/1978	48.793330	-9.839330	1.35	1	1	Irish	SW
+48-10	**3**	05/08/1978	48.817830	-9.756000	1.53	1	1	Irish	SW
+48-10	**13**	25/08/1978	48.998500	-9.976830	0.60	1	1	Irish	SW
+48-10	**22**	26/08/1978	48.962830	-9.679000	1.30	1	1	Irish	SW
+48-10	**23**	26/08/1978	48.934830	-9.768670	2.01	1	1	Irish	SW
+48-10	**37**	27/08/1978	48.847330	-9.655670	2.06	1	1	Irish	SW
+48-10	**38**	27/08/1978	48.875830	-9.564000	2.11	1	1	Irish	SW
+48-10	**39**	27/08/1978	48.903170	-9.468000	2.27	1	1	Irish	SW
+48-10	**54**	28/08/1978	48.881000	-9.952000	1.91	1	1	Irish	SW
+48-10	**68**	29/08/1978	48.729170	-9.638670	1.73	1	1	Irish	SW
+48-10	**113**	31/08/1978	48.615500	-9.616170	1.30	1	1	Irish	SW
+48-10	**114**	31/08/1978	48.585330	-9.708000	2.68	1	1	Irish	SW
+48-11	**1**	04/08/1978	48.931170	-10.567830	1.80	1	1	Irish	SW
+48-11	**2**	04/08/1978	48.844000	-10.448670	1.40	1	1	Irish	SW
+48-11	**3**	04/08/1978	48.875500	-10.357500	1.60	1	1	Irish	SW
+48-11	**7**	05/08/1978	48.815330	-10.112170	0.10	1	1	Irish	SW
+49-09	**6**	15/07/1977	49.915830	-8.750000	1.41	1	1	Irish	NW
+49-09	**7**	15/07/1977	49.836360	-8.915140	2.02	1	1	Irish	NW
+49-09	**49**	09/07/1978	49.797500	-8.916670	1.77	1	1	Irish	NW
+49-10	**16**	17/07/1978	49.475330	-9.168170	1.17	4	1	Irish	NW
+49-10	**17**	17/07/1978	49.446670	-9.263670	1.33	4	1	Irish	NW
+49-10	**18**	17/07/1978	49.420330	-9.355330	2.31	1	1	Irish	NW
+49-10	**19**	17/07/1978	49.306670	-9.337500	1.90	1	1	Irish	SW
+49-10	**20**	17/07/1978	49.274000	-9.437330	1.95	1	1	Irish	SW
+49-10	**82**	29/07/1978	49.070500	-9.303830	2.28	1	1	Irish	SW
+49-10	**83**	29/07/1978	49.043670	-9.400170	1.44	1	1	Irish	SW
+49-10	**84**	29/07/1978	49.016330	-9.492670	2.61	1	1	Irish	SW
+49-10	**85**	29/07/1978	49.076170	-9.696830	3.06	1	1	Irish	SW
+49-10	**86**	29/07/1978	49.104500	-9.605000	2.55	1	1	Irish	SW

+49-10	**89**	30/07/1978	49.131500	-9.508830	0.72	0	1	Irish	SW
+49-10	**90**	30/07/1978	49.159670	-9.413830	2.60	1	1	Irish	SW
+49-10	**91**	30/07/1978	49.186500	-9.327000	2.53	1	1	Irish	SW
+49-10	**95**	21/08/1978	49.332000	-9.244170	0.90	1	1	Irish	SW
+49-10	**96**	21/08/1978	49.215670	-9.227330	1.48	1	1	Irish	SW
+49-10	**97**	21/08/1978	49.251170	-9.521670	1.71	1	1	Irish	SW
+49-10	**104**	26/08/1978	49.029500	-9.560670	2.94	1	1	Irish	SW
+50-09	**62**	07/07/1978	50.233330	-8.273000	2.18	1	1	Irish	N
+50-09	**63**	07/07/1978	50.205170	-8.373170	2.73	1	1	Irish	N
+50-09	**65**	08/07/1978	50.056500	-8.449670	0.20	1	1	Irish	NW
+50-09	**66**	08/07/1978	50.028170	-8.553830	2.26	1	1	Irish	NW
+50-09	**78**	08/07/1978	50.001670	-8.648170	2.23	0	1	Irish	NW
									Total 42
UK sector adjacent to and SW of GLAMAR data coverage									
+48-10	**4**	06/08/1978	48.667330	-9.237670	1.30	1	1	UK	SW of multibeam mosaic
+48-10	**5**	06/08/1978	48.637500	-9.336330	1.78	1	1	UK	SW
+48-10	**6**	06/08/1978	48.610000	-9.427500	1.75	1	1	UK	SW
+48-10	**7**	06/08/1978	48.584170	-9.516670	0.85	1	1	UK	SW
+48-10	**8**	06/08/1978	48.435000	-9.396500	1.40	1	1	UK	SW
+48-10	**9**	07/08/1978	48.257670	-9.562330	4.47	1	1	UK	SW
+48-10	**40**	27/08/1978	48.926670	-9.377670	1.37	1	1	UK	SW
+48-10	**52**	28/08/1978	48.985830	-9.187500	0.91	1	1	UK	SW
+48-10	**69**	29/08/1978	48.755500	-9.541670	1.42	1	1	UK	SW
+48-10	**70**	29/08/1978	48.783500	-9.448500	1.38	1	1	UK	SW
+48-10	**71**	29/08/1978	48.809670	-9.356500	2.88	1	1	UK	SW
+48-10	**91**	30/08/1978	48.838830	-9.265500	1.78	1	1	UK	SW
+48-10	**92**	30/08/1978	48.868170	-9.171330	1.94	1	1	UK	SW
+48-10	**94**	30/08/1978	48.724500	-9.247670	1.28	1	1	UK	SW
+48-10	**110**	31/08/1978	48.865830	-9.343170	2.87	1	1	UK	SW
+48-10	**111**	31/08/1978	48.670000	-9.435500	1.50	1	1	UK	SW
+48-10	**112**	31/08/1978	48.642830	-9.528670	1.80	1	1	UK	SW
+48-10	**133**	01/09/1978	48.662330	-9.043830	0.50	1	1	UK	SW
+48-10	**134**	01/09/1978	48.636000	-9.138500	1.60	1	1	UK	SW
+48-10	**135**	01/09/1978	48.610000	-9.234000	1.15	1	1	UK	SW
+48-10	**136**	01/09/1978	48.582830	-9.329000	0.45	1	1	UK	SW
+48-10	**137**	01/09/1978	48.554500	-9.414500	0.10	1	1	UK	SW
+48-10	**154**	02/09/1978	48.544170	-9.021500	1.65	1	1	UK	SW
+48-10	**155**	02/09/1978	48.516330	-9.118330	0.66	1	1	UK	SW
+48-10	**156**	02/09/1978	48.492170	-9.213330	0.45	1	1	UK	SW
+48-10	**157**	02/09/1978	48.464330	-9.302670	0.46	1	1	UK	SW
+48-10	**173**	03/09/1978	48.286170	-9.466500	2.67	1	1	UK	SW
+48-10	**174**	03/09/1978	48.313500	-9.374170	1.48	1	1	UK	SW
+48-10	**175**	03/09/1978	48.342170	-9.281670	1.51	1	1	UK	SW
+48-10	**176**	03/09/1978	48.371170	-9.189830	2.26	1	1	UK	SW
+49-09	**2**	14/07/1977	49.916670	-8.076670	1.23	1	1	UK	E
+49-09	**3**	14/07/1977	49.829170	-8.234170	1.91	1	1	UK	SE
+49-09	**13**	16/07/1977	49.588330	-8.411670	0.61	1	1	UK	SE

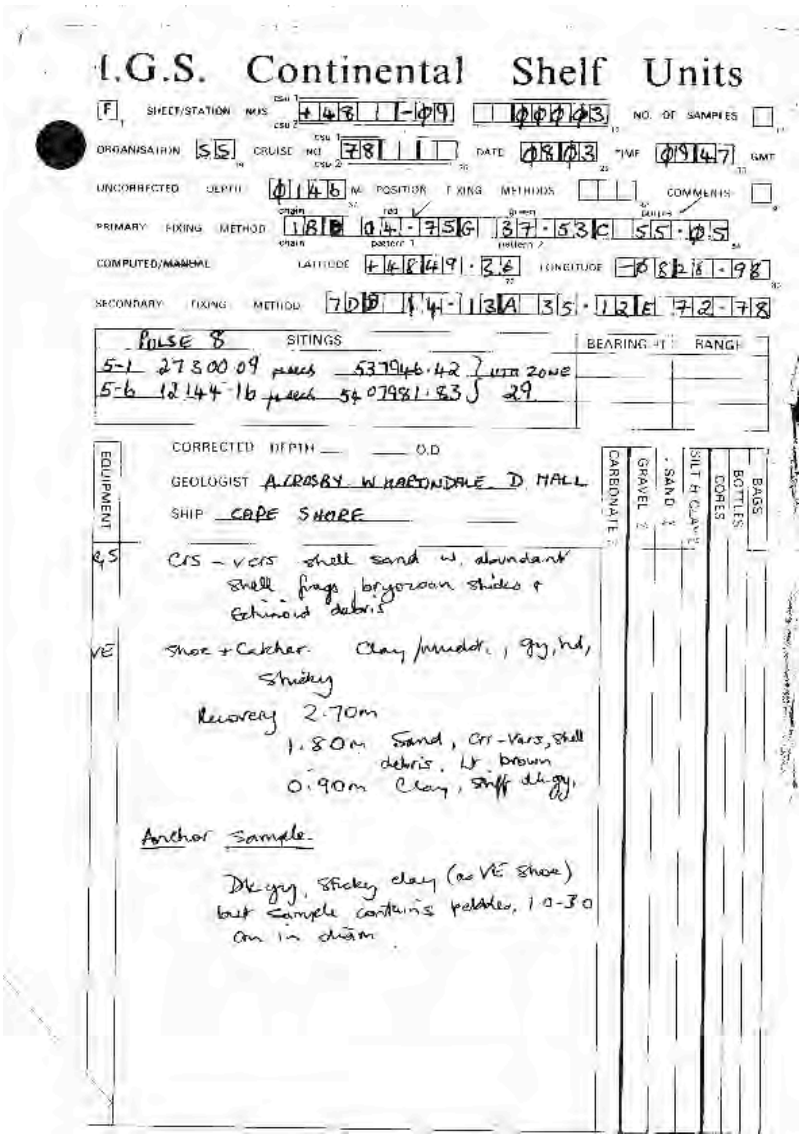
+49-09	**14**	16/07/1977	49.666670	-8.251670	0.62	1	1	UK	SE
+49-09	**15**	16/07/1977	49.750000	-8.081670	0.92	1	1	UK	SE
+49-09	**18**	16/07/1977	49.483330	-8.590000	0.61	1	1	UK	SE
+49-09	**24**	31/07/1977	49.334170	-8.645000	0.20	1	1	UK	SE
+49-09	**27**	31/07/1977	49.258340	-8.949170	0.60	1	1	UK	SE
+49-09	**28**	01/08/1977	49.336670	-8.795830	1.96	1	1	UK	SE
+49-09	**29**	01/08/1977	49.211670	-8.721670	0.97	1	1	UK	SE
+49-09	**40**	02/08/1977	49.050000	-8.833330	1.31	1	1	UK	SW
+49-09	**41**	02/08/1977	49.166670	-8.818330	1.25	1	1	UK	SE
+49-09	**136**	12/08/1978	49.699500	-8.409330	1.71	1	1	UK	SE
+49-09	**138**	12/08/1978	49.667170	-8.367000	0.40	1	1	UK	SE
+49-09	**151**	13/08/1978	49.610830	-8.293830	0.60	1	1	UK	SE
+49-09	**152**	13/08/1978	49.555330	-8.487670	0.50	1	1	UK	SE
+49-09	**153**	13/08/1978	49.527000	-8.584000	4.70	1	1	UK	SE
+49-09	**154**	13/08/1978	49.406170	-8.567330	1.00	1	1	UK	SE
+49-10	**1**	31/07/1977	49.300000	-9.133330	1.37	1	1	UK	SW
+49-10	**2**	31/07/1977	49.245000	-9.076670	1.41	1	1	UK	SW
+49-10	**3**	31/07/1977	49.201500	-9.150000	1.13	1	1	UK	SW
+49-10	**79**	21/07/1978	49.153500	-9.020170	1.65	1	1	UK	SW
+49-10	**80**	21/07/1978	49.127830	-9.115830	0.66	1	1	UK	SW
+49-10	**81**	21/07/1978	49.097500	-9.211830	1.76	1	1	UK	SW
+49-10	**103**	22/08/1978	49.013170	-9.099000	1.86	1	1	UK	SW
+50-09	**24**	13/07/1977	50.248330	-8.011670	2.00	1	1	UK	N
+50-09	**25**	13/07/1977	50.158330	-8.270000	2.17	1	1	UK	NW
+50-09	**33**	14/07/1977	50.056670	-8.100000	2.30	1	1	UK	E
									Total 58
									TOTAL STATIONS: 150

APPENDIX B – INFORMATION FROM BGS SAMPLE STATION FIELD LOGS

Summary of information from field logs of 29 sample stations from the Irish-UK sectors (obtained from BGS via the RIDGES Digital Data Licence): 12 stations correspond to vibrocores shown to contain glacigenic sediments (see Fig. 2 for locations) and 17 others lie within the GLAMAR multibeam coverage. An example of a field log follows the listing.

ID	Lat	Long	Sec-tor	TD (m)	Date	Depth (m)	Log description	Basal facies (Scourse et al. 1990)	Multi-beam depth (m)	MB-Log (m)
Containing suspected glacigenic sediments										
49/-09/12	49.7500	-8.4117	UK	0.49	16/07/1977	151	0.49 m sand (silty, cser to base); in shoe, gritty clay over diamict	Melville Till	137	-14
49/-09/21	49.4208	-8.1058	UK	1.14	30/07/1977	144	0.44 m sand / 0.7 m plastic grey clay	Melville Till		
49/-09/43	49.9940	-8.2375	UK	1.88	08/07/1978	127	1.64 m sand (f-m) / 0.24 m diamict (silt w/ pebbles)	Melville Till	132	5
49/-09/44	49.9633	-8.3373	UK	5.40	08/07/1978	127	5.3 m sand (fine, muddy, shelly) / 10 cm clay (sandy, silty, firm)	Melville Laminated Clay / Melville Till	121	-6
49/-09/137	49.7535	-8.2135	UK	1.51	12/08/1978	118	1.51 m sand (cser down) / 8 cm diamict in shoe (stiff clayey sand w/ rounded pebbles)	Melville Till	132	14
48/-09/3	48.8227	-8.4830	UK	2.70	03/08/1978	146	1.8 m sand (cse, shell debris) / 0.9 m clay (stiff, dk grey); + anchor sample w/ pebbles 1-3 cm	Melville Laminated Clay (glacimarine)		
49/-09/90	48.5333	-8.9842	Irish	1.55	15/07/1978	137	1.2 m sand & gravel / 0.35 m stiff grey clay	Melville Laminated Clay	140	3
48/-09/148	48.5493	-8.5633	UK	0.89	28/07/1979	183	0.32 m sand (fine, br, shell frags) / 0.36 m sand (shelly, green) / 0.21 m silt (sandy, green - organics?)	Melville Laminated Clay		
48/-10/93	48.8978	-9.0747	UK	1.56	30/08/1978	147	0.61 m sand (f-med, br, shell debris) / 0.95 sand (clayey, shelly, greenish-grey, compact)	Melville Laminated Clay		
48/-09/137	48.3250	-8.9933	UK	1.53	27/07/1979	210	1.15 m sand (fine, silty, grey-green) / 0.3 m sand (fine, shelly, green) / 0.08 m clay (sl. silty, pebbly, green)	"proximal glaciomarine or lodgement till affinities"		
48/-10/53	48.9065	-9.8620	Irish	2.27	28/08/1978		1.25 m sand (f-med, br, shell debris) / 0.96 m sand (fine, muddy, grey) / 0.06 m clay (grey, plastic)	"proximal glaciomarine or lodgement till affinities"		
48/-10/51	48.9575	-9.2850	UK	1.34	28/08/1978	146	0.96 m sand (med, shelly, cse & gravelly to base) / 0.38 m sand (clayey, green, shells, compact)	Upper Little Sole Fm (Early Pleist)?		
Within GLAMAR multibeam coverage										
48/-11/4	48.9042	-10.2642	Irish	2.80	04/08/1978	135	2.8 m sand (v-vf, clayey, dk grey)			
48/-11/5	48.9367	-10.1637	Irish	1.50	04/08/1978	124	1.5 m sand (fine, muddy, dk grey)			
48/-11/6	48.8483	-10.0480	Irish	3.70	05/08/1978	175	3.7 m sand (v-vf, clayey, dk grey)			
49/-09/50	49.6502	-8.9972	Irish	2.53	09/07/1978	142	2.53 m sand (silty to v. silty, green)		144	2
49/-09/75	49.7072	-8.8048	Irish	3.10	14/07/1978	109	3.1 m sand (fine, clean, grey-green)		113	4
49/-09/89	49.6777	-8.9030	Irish	3.20	15/07/1978	111	3.2 m sand (fine, clean, grey, shell debris)		114	3

49/-09/96	49.6180	-8.6953	UK	2.09	15/07/1978	127	2.09 m sand (f-m, grey-brown, gravelly towards base)		132	5
49/-09/97	49.5907	-8.7948	UK	3.10	16/07/1978	135	3.1 m sand (med, grey, brown)		138	3
49/-09/99	49.4158	-8.9672	UK	4.26	18/07/1978	146	4.26 m sand (fine, grey, muddy at top)		136	-10
49/-09/135	49.7893	-8.5183	UK	2.19	12/08/1978	109	2.19 m sand (med-f., shelly)		123	14
49/-10/94	49.3573	-9.1530	Irish	2.21	21/08/1978	113	2.21 m sand (med., clean, olive grey, shells)		140	27
50/-09/26	50.1633	-8.3817	UK	1.76	13/07/1977	128	0.3 m sand (sl. muddy) / 1.46 m sand (cse, clean, shelly)			
50/-09/27	50.1150	-8.3783	UK	2.90	13/07/1977	143	1.0 m mud (silty, sandy, grey) grading down to 1.9 m clay (soft, grey)			
50/-09/29	50.0633	-8.3767	UK	1.15	13/07/1977	144	0.1 m silt (muddy) / 0.75 m sand (silty) / 0.3 m sand (med-cse), oyster shell frags in shoe			
50/-09/32	50.0217	-8.1708	UK	2.25	14/07/1977	134	2.25 m silt (sl. sandy, muddy, uniform)		126	-8
50/-09/64	50.1775	-8.4735	Irish	3.05	07/07/1978	127	3.05 m sand (m-f, grey, muddy)			
50/09/67	50.0118	-8.3965	UK	2.30	08/07/1978		2.3 m sand (fine, grey-green)		128	



I.G.S. Continental Shelf Units

SHEET/STATION NOS +48 -09 ØØØ3 NO. OF SAMPLES
ORGANISATION 55 CRUISE NO 78 DATE Ø8Ø3 TIME Ø947 GMT
UNCORRECTED DEPTH Ø146 M POSITION FIXING METHODS COMMENTS
PRIMARY FIXING METHOD 1BB 04·75G 37·53C 55·Ø5
COMPUTED/MANUAL LATITUDE +4849·36 LONGITUDE -0828·98
SECONDARY FIXING METHOD 7DD 14·13A 35·12E 72·78

PULSE 8 SITINGS BEARING RANGE
5-1 273009 ... 5379.46·42 } UTM ZONE
5-6 1214416 ... 5407981·83 } 29

CORRECTED DEPTH ... O.D
GEOLOGIST A CROSBY W HARTONDALE D HALL
SHIP CAPE SHORE

EQUIPMENT | CARBONATE | GRAVEL | SAND | SILT & CLAY | CORES | BOTTLES | BAGS

GS Crs – vcrs shell sand w. abundant shell frags bryozoan sticks & Echinoid debris

VE Shoe + Catcher. Clay/mudst, gy, hd, sticky
Recovery 2.70m
1.80m Sand, Crs-Vcrs, shell debris, Lt brown
0.90m Clay, stiff dk gy.

Anchor Sample.
Dk gy, sticky clay (as VE shoe) but sample contains pebbles, 10-30 cm in diam

Example of BGS sample station field log.

APPENDIX C – LISTING OF GEOPHYSICAL PROFILES (BGS, NOCS)

Metadata listing of shallow geophysical profiles identified on the mid- to outer shelf of the UK and Irish sectors of the Celtic Sea, across the GLAMAR/RIDGES area of interest (see box in Fig. 7). Multi-parameter profiles (airgun, sparker, pinger) were acquired by BGS in the 1970s and boomer profiles by the national Institute of Oceanography, now NOCS, in the 1960s. Scanned images of the sparker, boomer and pinger profiles highlighted in orange were obtained from BGS through the RIDGES Digital Data Licence (see examples in Fig. 8).

1. Geophysical profiles acquired by BGS

Cruise	Line	SOL (Long)	SOL (Lat)	EOL (Long)	EOL (Lat)	Orien-tation	Air-gun	Spar-ker	Pin-ger	Len-gth (km)	Irish sector (km)	Comment
												VC = vibrocore site
crossing GLAMAR multibeam & seismic data (Irish-UK sectors)												
1978/4	**11**	-10.3842	48.8891	-9.4048	48.1352	NW-SE	1	1	1	111	67	crosses GLAM01 sparker
1978/4	**25**	-7.9738	49.4640	-10.5332	48.6971	SW-NE	1	1	1	206	101	crosses GLAM01 sparker & VC 48/10/53, VC 49/09/21
1978/4	**27**	-7.9476	49.3273	-8.7369	49.9683	NW-SE	0	1	1	91	15	
1978/4	**28**	-8.5913	50.0669	-7.9622	49.5564	NW-SE	0	1	1	73	9	crosses VC 49/09/137
1978/4	**29**	-7.9065	49.6173	-8.5455	50.1370	NW-SE	0	1	1	74	14	crosses VC 49/09/44
1978/4	**30**	-8.4856	50.1772	-7.9179	50.3370	SW-NE	0	1	1	44	22	
1978/4	**33**	-8.3943	50.2302	-7.7237	49.6826	NW-SE	1	1	1	78	8	
1978/4	**40**	-9.2750	49.4603	-8.1368	48.5387	NW-SE	1	1	1	132	19	crosses VC 48/09/3
1978/4	**48**	-7.5834	49.9334	-9.3466	49.4308	SW-NE	1	1	0	139	35	crosses VC 49/09/137 & 49/09/90
1978/4	**55**	-10.5758	48.7885	-9.9198	48.9952	SW-NE	1	1	0	54	54	crosses GLAM01 sparker, VC48/11/4
1978/4	**57**	-8.7193	49.9809	-7.8026	50.2301	SW-NE	1	1	0	71	25	
1978/4	**58**	-7.7243	50.1362	-8.9308	49.7949	SW-NE	1	1	0	95	25	crosses VC 49/09/43 & 49/09/44
1978/4	**59**	-8.8722	49.8649	-7.4871	48.7341	NW-SE	1	1	0	161	14	
1978/4	**60**	-7.6565	48.6642	-8.9839	49.7493	NW-SE	1	1	0	155	12	
1978/4	**61**	-9.1307	49.6557	-7.7555	48.6132	NW-SE	1	1	0	154	23	
1978/4	**65**	-8.6786	49.1898	-9.1610	49.5838	NW-SE	1	1	0	56	12	
1978/4	**66**	-9.1306	49.6165	-8.3245	49.8477	SW-NE	1	1	0	64	30	
1978/4	**68**	-7.9787	49.7019	-9.5717	49.2424	SW-NE	1	1	0	127	40	
1978/4	**69**	-9.7508	49.0572	-7.9848	49.5745	SW-NE	1	1	0	141	44	
1979/12	**15**	-7.7939	49.8406	-8.3591	50.2991	NW-SE	1	1	1	65	18	
1979/12	**16**	-8.4830	50.1965	-7.9844	49.7963	NW-SE	1	1	1	58	9	crosses VC 49/09/43
1979/12	**17**	-8.0436	50.0048	-8.5809	49.8946	SW-NE	1	1	1	41	0	
1979/12	**18**	-8.6787	50.0196	-7.9684	49.4594	NW-SE	1	1	1	81	7	
1979/12	**39**	-9.2882	48.1475	-10.3974	49.0097	NW-SE	1	1	1	127	74	crosses GLAM01

												sparker
SW of GLAMAR data, across seaward extension of ridges (Irish-UK sectors)												
1978/4	**10**	-9.5399	48.1527	-10.7915	49.0611	NW-SE	0	1	1	138	106	
1978/4	**26**	-10.2896	48.5329	-7.9182	49.2222	SW-NE	0	1	1	191	56	crosses VC 48/10/93
1978/4	**39**	-8.7858	48.8615	-9.4196	49.3773	NW-SE	1	1	1	74	24	
1978/4	**49**	-9.5686	49.2736	-8.5255	48.4369	NW-SE	1	1	0	121	31	crosses VC 48/10/93
1978/4	**50**	-8.6802	48.3635	-9.6568	49.1525	NW-SE	1	1	0	114	30	
1978/4	**51**	-9.8046	49.0690	-8.8876	48.3280	NW-SE	1	1	0	107	34	
1978/4	**52**	-9.0469	48.2468	-9.9925	49.0095	NW-SE	1	1	0	110	44	
1978/4	**53**	-6.0485	49.1383	-9.9826	48.0443	SW-NE	1	1	0	315	0	crosses VC 48/09/137
1978/4	**54**	-9.7683	48.1396	-10.6442	48.8355	NW-SE	1	1	0	102	73	
1978/4	**56**	-10.1316	48.9071	-9.1700	48.1740	NW-SE	1	1	0	109	60	
1978/4	**63**	-8.4341	48.8834	-10.1504	48.3938	SW-NE	1	1	0	138	45	
1978/4	**64**	-10.3907	48.5700	-8.7426	49.0992	SW-NE	1	1	0	135	82	passes near VC 48/10/51
1979/12	**40**	-9.8611	49.0084	-8.9829	48.3227	NW-SE	1	1	1	100	30	crosses VC 48/09/137 (SE end of line)
Regional lines (Irish sector)												
1971/3	**P**	-8.3864	51.5402	-12.0056	50.4833	W-E	0	1	0	282	282	N Celtic Sea (Irish)
1971/3	**Q**	-12.2555	50.5250	-7.7910	51.2278	W-E	0	1	0	325	325	N Celtic Sea (Irish)
										4759	**1899**	**TOTAL KMS**

2. Geophysical profiles acquired by NIO (now NOCS)

SOL date	SOL time	EOL date	EOL time	SOL (Lat)	EOL (Lat)	SOL (Lat)	EOL (Long)	Boo-mer	Length (km)	Irish sector (km)	Comment
18/08/1962	1200	19/08/1962	0600	49.6641	-8.1290	50.2248	-10.3896	1	183	128	SE to NW across UK & Irish sectors; crosses GLAMAR multibeam area
29/08/1962	0000	30/08/1962	0800	50.8290	-8.1124	47.6778	-7.2117	1	403	79	N to S across the Irish, UK and French sectors
02/09/1962	1500	03/09/1962	1500	49.2008	-8.1977	49.4404	-9.3601	1	238	160	SE to NW across UK & Irish sectors; crosses GLAMAR multibeam area, zig-zigs across Cockburn Bank
									824	**367**	**TOTAL KMS**

APPENDIX D – LISTING OF GLAMAR GEOPHYSICAL PROFILES

Listing of GLAMAR Chirp profiles and 22 corresponding sparker profiles (cf. Fig. 2). Chirp profile names refer to the original acquisition file names, which were concatenated into logical lines where necessary. Not all Chirp profiles contain subbottom information, mainly due to acquisition in rough conditions; of 205 profiles acquired, 140 were loaded into SMT Kingdom Suite and a further 29 were found to have no subbottom reflections. The maximum number of reflections seen on each of the remaining 111 Chirp profiles is indicated below; the distribution of profiles containing 3 or more reflections is shown in the figures following the listing.

Sparker profile ID	**Chirp profile ID**	**# sub-seabed horizons visible on Chirp**	**Note**
GLAM01a	CH1-4		SW of main area
GLAM01b	CH5-8		"
GLAM01c	CH9-14		"
GLAM02a	CH15-18		"
GLAM02b	CH19-22		"
GLAM01d	CH23-27		"
GLAM01e	CH28-32		"
GLAM01f	CH33-37	1	
GLAM01g	CH38-42	3	
GLAM01h	CH43-48	3	
GLAM03a	CH49-51	4	
GLAM03b	CH52-55	4	crosses VC 49/-09/44; possible core site
GLAM03c	CH56-58	4	crosses VC 49/-09/137
	CH59		NOT LOADED
GLAM04a	CH60-64	3	crosses VC 49/-09/137 & 12
GLAM04b	CH65-69	3	
	CH70		NOT LOADED
	CH71-73	2	
	CH74-76	2	
	CH77-79	2	
	CH80-82	2	
	CH83-85	3	
	CH86-88	3	
	CH89		NO FILE?
	CH90-92	2	
	CH93-96	3	
GLAM05	CH97-99	2	
GLAM06	CH100-102	2	
GLAM07	CH103-104	2	
GLAM08	CH105-110		Chirp NOT LOADED
GLAM09	CH111-117	2	
	CH118-120	2	
	CH121-123	2	
	CH124-128	3	

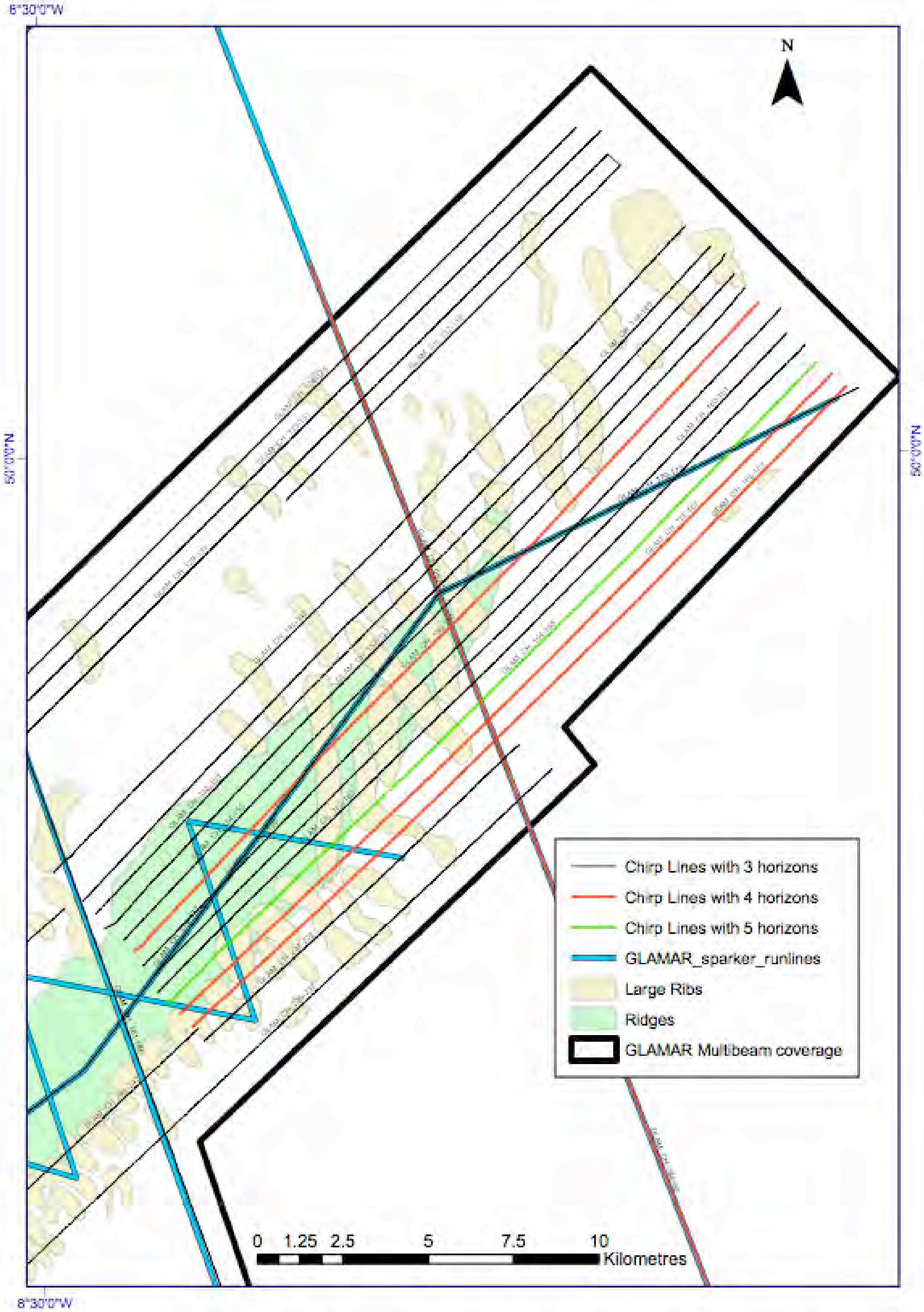
	CH129-131	3	
	CH132-133	3	
	CH134-135	2	
	CH136-137	2	
	CH138-139	2	
	CH140-141		
	CH142-143	2	
	CH144-145	3	
	CH146-147	2	
	CH148-149	3	
	CH150-151	3	
	CH152-153	3	
	CH154-155	3	
	CH156-157	4	
	CH158-159	3	
	CH160-161	3	
	CH162-163	3	crosses VC 49/-09/43
	CH164-165	5	possible core site
	CH166-167	4	possible core site
	CH168-169	4	possible core site
GLAM10a	CH170-173	3	crosses VC 49/-09/43 & 44
GLAM10b	CH174-177	3	
	CH178-180		NOT LOADED
GLAM11a	CH181-185	3	crosses VC 49/-09/12
GLAM11b	CH186-188	3	
	CH189-190		
GLAM12	CH191-195	1	
GLAM13	CH196-198	2	
	CH199-201		
GLAM15a	CH202-205	2	
GLAM15b	CH206-208	1	
GLAM15c	CH209-212	3	crosses VC 49/-09/90
GLAM16a	CH215-216		Chirp NOT LOADED
GLAM16b	CH217-221	3	
GLAM17	CH222-223	2	
GLAM18	CH224-225	2	
GLAM19	CH226-227	1	
GLAM20	CH228		Chirp NOT LOADED
GLAM21	CH229		Chirp NOT LOADED
GLAM22	CH230		Chirp NOT LOADED
	CH231-232	3	
	CH233-234	4	
	CH235-237	3	
	CH238		
	CH239-240	2	
	CH241-242	3	
	CH243		NOT LOADED
	CH244		NOT LOADED
	CH245		NOT LOADED
	CH246-247	2	
	CH248		NOT LOADED

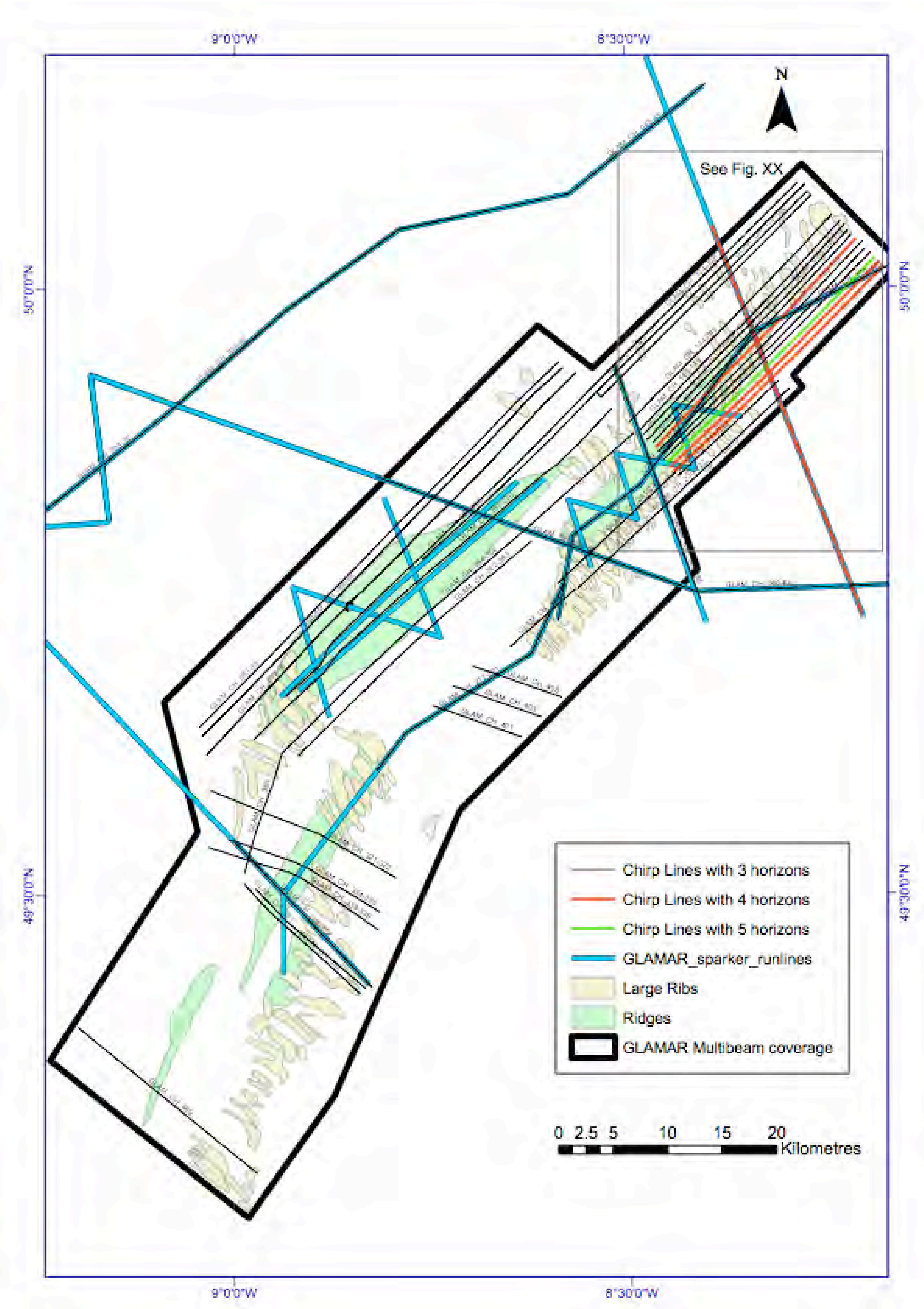
	CH249		NOT LOADED
	CH250		NOT LOADED
	CH251-252	2	
	CH253		NOT LOADED
	CH254-255	2	
	CH256		NOT LOADED
	CH257		NOT LOADED
	CH258-259	1	
	CH260		NOT LOADED
	CH261-263	2	
	CH264-266		NOT LOADED
	CH267-270	3	
	CH271-273		NOT LOADED
	CH274-277		NOT LOADED
	CH278-281		NOT LOADED
	CH282-285		NOT LOADED
	CH286-290		NOT LOADED
	CH291-294	1	
	CH295-297		
	CH298-300		
	CH301-302		
	CH303-305		
	CH306-307		
	CH308		
	CH309		NOT LOADED
	CH310-311		NOT LOADED
	CH312-313		
	CH314-316		
	CH317-318		
	CH319-320		
	CH321-322	3	
	CH323-325		NOT LOADED
	CH326-327		
	CH328-329		
	CH330-331		
	CH332-333		
	CH334-335	3	
	CH336-337	2	crosses VC 49/-09/90
	CH338-339	3	
	CH340-341		NOT LOADED
	CH342-343	2	
	CH34-345		NOT LOADED
	CH346-347		
	CH348	1	
	CH349		
	CH350	2	
	CH351	3	
	CH352	3	
	CH353	3	crosses VC 49/-09/90
	CH354-356	3	
	CH357-361		NOT LOADED

	CH362-363	3	
	CH364-366		NOT LOADED
	CH367-368	2	
	CH369-371		NOT LOADED
	CH372-373		
	CH374-376		NOT LOADED
	CH377-378	2	
	CH379-381		NOT LOADED
	CH382-383		
	CH384-387		NOT LOADED
	CH388-389		NO FILE?
	CH390		NOT LOADED
	CH391		NOT LOADED
	CH392		NOT LOADED
	CH393	1	
	CH394		NOT LOADED
	CH395		
	CH396		NOT LOADED
	CH397	1	
	CH398	2	
	CH399	1	
	CH400		NOT LOADED
	CH401	3	
	CH402	2	
	CH403	3	
	CH404	2	
	CH405	3	
	CH406	2	
	CH407	2	
	CH408	3	
	CH409-410	2	
	CH411	1	
	CH412-413		NOT LOADED
	CH414-415	1	
	CH416-417		NOT LOADED
	CH418-419	2	
	CH420-422		NOT LOADED
	CH423-424	2	
	CH425-426		NOT LOADED
	CH427		
	CH428		
	CH429		NOT LOADED
	CH430		NOT LOADED
	CH431		
	CH432		
	CH433		
	CH434		NOT LOADED
	CH435		NOT LOADED
	CH436		
	CH437		NOT LOADED
	CH438		NOT LOADED

	CH439		
	CH440		NOT LOADED
	CH441		NOT LOADED
	CH442	2	
	CH443	1	
	CH444	1	
	CH445-446		NOT LOADED
	CH447-449	2	
	CH450-451	2	
	CH452-453		NOT LOADED
	CH454-455	2	
	CH456-457		NOT LOADED
	CH458-459	1	
	CH460-461	2	
	CH462-463		NOT LOADED
	CH464		NOT LOADED
	CH465		NOT LOADED
	CH466		NOT LOADED
	CH467-468		NOT LOADED
	CH469	3	
	CH470-471	1	
	CH472	2	
	CH473		NOT LOADED
	CH474	2	
	CH475-476	1	

APPENDIX D continued………………………………………………………………




9°0'0"W
8°30'0"W
50°0'0"N
49°30'0"N
N
See Fig. XX
Chirp Lines with 3 horizons
Chirp Lines with 4 horizons
Chirp Lines with 5 horizons
GLAMAR_sparker_runlines
Large Ribs
Ridges
GLAMAR Multibeam coverage
0 2.5 5 10 15 20
Kilometres