Reconnaissance Survey of the Irish Continental Shelf/Shelf Edge

Atlantic Irish Regional Survey (AIRS) 1996

A GLORIA Survey of the Irish Continental Margin

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Reconnaissance Survey of the Irish Continental Shelf/Shelf Edge (AIRS'96).

Abstract

The Atlantic Irish Regional Survey (AIRS96) sidescan sonar survey was carried out in August 1996. Covering an area of 200,000 km^2 it represented the largest reconnaissance seabed survey of the Irish Continental Shelf region. It covered both margins, together with much of the basin floor, of the Irish sector of the Rockall Trough and extended into the northern part of the Porcupine Seabight.

The objectives of this project were two fold:

1. *Strategic:*

- *to undertake, for the first time a preliminary reconnaissance survey of the Irish Continental Shelf/Shelf Edge,*
- *to establish a strategic database on Shelf/Slope Edge conditions,*
- *to provide training and experience to Irish researchers in state of the art marine surveying equipment (GLORIA) and data processing.*

2. *Scientific:*

- *to document slope stability and mass wasting features on the margins of the Rockall Trough,*
- *to map, where possible, occurrences of deep water carbonate mounds,*
- *to investigate the sediment erosional, transport and depositional mechanisms that have shaped the present morphology of the region.*

The survey revealed a range of sedimentary features across the steep (i.e. >6º slope) margins and the basin floor in the Rockall Trough. Four classes of sedimentary feature are recognised: (1) mass failure, (2) canyon systems, (3) sediment fans, and (4) sediment drifts. The western margin is characterised by large-scale downslope mass movement features. The western and central parts of the basin floor in the Rockall Trough contain the Feni Sediment Ridge, a large Miocene-Recent contourite sediment accumulation draped by large sediment waves trending sub-parallel to the dominant modern current pattern. A large-scale downslope mass failure feature is recognised across 14,000 km^2 of the northeastern margin of the Rockall Trough. Smaller slides and slumps occur along the eastern margin in association with more prevalent canyon, channel and fan systems. A cluster of carbonate mounds was imaged in the northern part of the Porcupine Seabight. These represent part of one of the most extensive suites of deep-water carbonate mounds in the Atlantic Margin and are currently the subject of a number of new EU-funded research projects.

Strong northward-directed bottom currents along the eastern margin are suggested to erode, circulate and re-deposit sediment on the basin floor and on the western margin of the Rockall Trough. The main terrigenous sedimentary input was from the Irish Mainland Shelf. A broad interplay of alongslope and downslope sediment transport processes shaped the morphology of the Rockall Trough, while tectonically-driven basin subsidence, Quaternary glaciations and glacio-eustatic sea-level fluctuations also influenced the overall sedimentation pattern in the Rockall Trough.

A list of deliverables of this project is contained in Appendix I.

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INTRODUCTION

The Irish Continental Shelf, a very extensive offshore region lying to the west of Ireland, has the potential to contain very significant amounts of mineral resources and hydrocarbons. It also has vast fisheries potential. It is increasingly regarded by the international marine scientific community as a very major natural laboratory containing important and fragile ecosystems such as the poorly understood deep water carbonate mounds and cold water coral reefs. During the past decade extensive marine research has taken place in continuous continental shelf regions to the north in UK and Norwegian waters, but the Irish region has been lightly explored and, until recently had little comparable high quality seabed and marine data.

In early 1996, two actions were undertaken:

1. A desk study on the feasibility and logistics of conducting a reconnaissance GLORIA (Geological LOng Range Inclined Asdic) survey of selected parts of the Irish Continental Shelf was carried out by project partners comprising the Dublin Institute for Advanced Studies (DIAS), University College Dublin (UCD) and the Geological Survey of Ireland (GSI).

2. A bibliography of existing data on the geology and geomorphology of the shelf to the west of Ireland was prepared (Vermeulen 1997).

In August 1996, the AIRS (Atlantic Irish Regional Survey) acquisition took place. Although this was a reconnaissance survey, it was the most significant and comprehensive sea floor survey of the deep-water basins to the west of Ireland undertaken so far. The geological and geophysical analysis of the results were carried out by the Department of Geology UCD and the Geophysics Section in DIAS.

During the course of the data analysis regular meetings of the researchers, partners and the steering committee took place. The steering committee consisted of representatives of the Marine Institute, the Marine Data Centre, the Petroleum Affairs Division (PAD) of the Department of the Marine and Natural Resources, GSI, DIAS and UCD.

The project was funded largely under the Marine Research Measure of the Operational Programme for Fisheries (1994-1999), with additional funding from the Marine Institute, the GSI and the PAD. Southampton Oceanographic Centre (SOC) provided access and technical assistance during acquisition and processing under the EU's Human and Capital and Mobility, Access to Large Scale Facilities Programme.

AIMS AND OBJECTIVES

The overall objective of the AIRS96 project was to analyse the morphology of modern sedimentary successions in the Rockall Trough and the northern part of the Porcupine Seabight using GLORIA sidescan sonar images.

The strategic aims of the survey were the following:

- To undertake a reconnaissance survey of the Irish (European) Shelf/Shelf Edge using GLORIA.
- To establish a strategic database on the Irish (European) Shelf/Shelf Edge accessible to Irish and European scientists.
- To provide training in the collection, processing and interpretation of GLORIA data thereby upgrading Irish marine science capability.
- To provide GLORIA data to Irish research institutions for value-added processing, training and education.

A number of specific scientific objectives were defined and addressed during the project. These included:

- documenting mass wasting, slope failure features in a region which is transitional from glaciated to non-glaciated margin, and involves channels, canyons, sediment lobes, slides and slumps;
- documenting and analysing slope stability on the margins of the Rockall Trough;
- identifying and mapping, where possible, occurrences of deep water carbonate mounds;
- mapping large-scale structural trends through the region and investigating their relationship with underlying structural control using other available geophysical information;
- investigating the sediment erosional, transport and depositional mechanisms that have shaped the present morphology of the region.

Since the late 1960s, the GLORIA (Geological LOng Range Inclined Asdic) sidescan sonar instrument (see Figure 1) has been used to survey about 10% of the world's deep oceans. It is a reconnaissance deep-sea mapping tool with the ability to cover in excess of 10,000 km^2 daily (depending on water depth and cruise speed). The GLORIA system is a shallow-towed, conventional sidescan sonar system operating at around 6.5 kHz. The sonar tool is described by Laughton (1981) and Somers (1996). Data processing techniques are detailed by Chavez (1986), Searle *et al.* (1990) and Le Bas & Masson (1994).

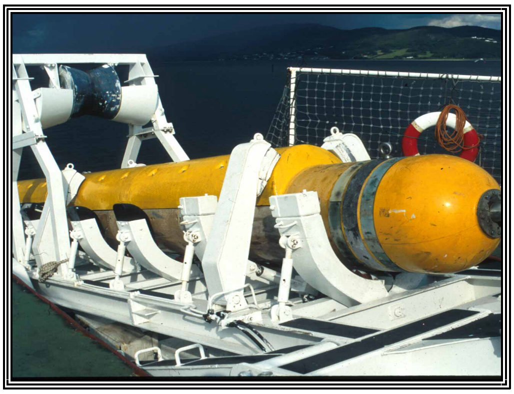

Figure 1: GLORIA sidescan sonar system mounted on the aft deck of the MV Siren before departing on the AIRS96 cruise.

GLORIA sidescan sonar images have a pixel resolution of 50 m and are displayed as monochrome images. The grey scale variations represent energy received from the sea-bed by the transducers (see Figure 2). This “backscatter” energy is expressed on GLORIA images as tonal variations with strong backscatter producing lighter tones and weak backscatter producing darker hues. This variation is caused by a complex range of factors, such as seafloor slope, topographic variability, grazing angle of insonification (geometry of the sensor-target system), physical characteristics of the target surface (e.g. surface roughness), and the intrinsic nature of the target (variations in sediment composition; Ulrick 1983). Scattering from volume inhomogeneities and subbottom interfaces associated with stacked sediment layers also affects GLORIA backscatter intensity. The implication of these lithological properties is that any reliable ground-truthing of GLORIA images by sampling is not feasible in complex areas. Individual samples (few m^2) would not be representative of backscatter intensity of a single pixel (2,500 m^2). Only in morphologically simple regions (flat with no lateral and vertical lithological variation), close to the ship’s track (at far range even micro-topography affects backscatter intensity), would bottom sampling aid ground-truthing of the sonar images. This difficulty of ground-truthing GLORIA sonar images adds a degree of ambiguity of sonar data interpretation.

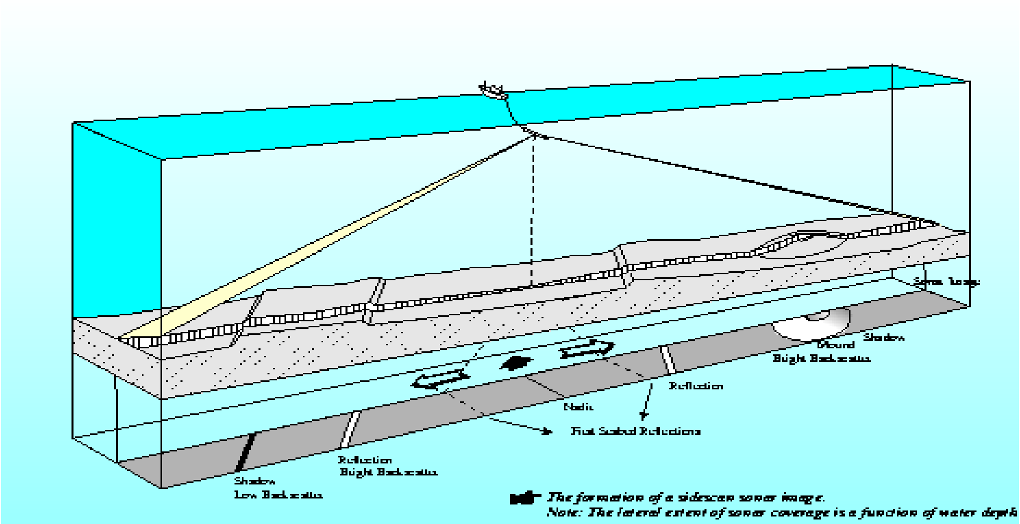

Figure 2: Sidescan sonar surveying technique. The GLORIA sonar is towed at a distance of 300m from the ship, at 50 m water depth. The acoustic pulse forms a “butterfly” shaped imprint on the sea-floor with progressively larger area covered away from the ship’s track.

DATA ACQUISITION

The data acquisition for the AIRS96 took place from 10th August to 4th September 1996. The survey vessel, the MV Siren, embarked from Rathmullan in County Donegal and returned to Dublin port at the end of the survey.

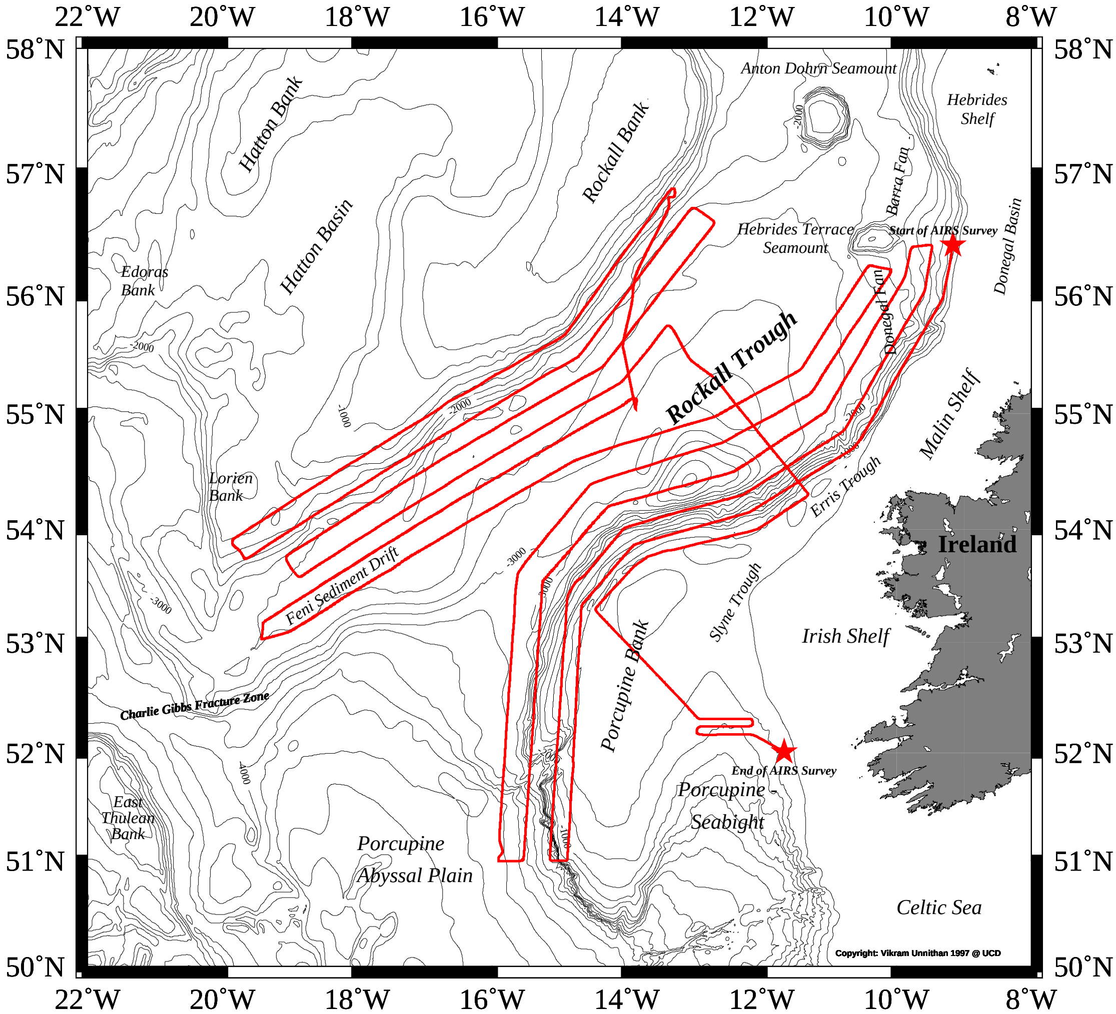

Figure 3: AIRS96 survey tracks.

The AIRS96 survey initially concentrated on the margins of the Rockall Trough with survey lines parallel to the margins (see Figure 3). The swath width averaged 32 km with a nominal track separation of 25 km, to ensure overlap between adjacent swaths. The analysis was complicated by the very steep slopes (locally in excess of 20°) along the southeastern margin in the survey area. Tracklines were oriented parallel to the bathymetric contours (slope margin), which meant that signal response levels were higher from the upslope regions than from the downslope side. A further complication, in terms of image resolution and interpretation, is the degree of acoustic penetration. The signal to noise ratio was quite low during the survey especially in the areas with thick unconsolidated sediments on the Trough floor. Various studies (Gardner *et al.* 1991) show that the GLORIA signal penetrates the seafloor to varied depths, depending on the nature of the sub-bottom materials.

In addition to the GLORIA tool, a 3.5 kHz profiler was also deployed. This has a vertical resolution of 0.8 m and in areas of soft unconsolidated sediments penetrates to a maximum depth of 80 m. The echosounder data is useful as it compensates for the lack of GLORIA coverage directly under the ship's tracks. It also provides accurate depth values needed for the sonar processing. Bathythermograph (XBT and XSV) probes were deployed at 6 hour intervals during the cruise. These probes provide information on the degree of water column stratification. This data is required for swath bathymetry processing.

DATA PROCESSING

The post-cruise data processing was carried out at the Southampton Oceanography Centre (SOC) by Vik Unnithan and Keith McGrane under the supervision of experienced SOC staff. This took a total of 10 weeks and the main objectives were to:

- process GLORIA sidescan sonar data
- process GLORIA swath bathymetry data
- gain expertise with the Erdas Imagine and WHIPS (now called PRISM) software and with UNIX operating system
- document the processing techniques for future reference by other scientists.

The processing was divided into (a) Sonar Image processing and (b) Swath Bathymetry processing. In addition to processing the AIRS96 sonar data, older GLORIA datasets from the Porcupine Seabight were digitised and processed. After completion of all the sonar image mosaicing, swath bathymetry processing carried out synchronously with archiving the data on CD-ROMs.

Sonar Image Processing

Initial processing of the sonar images was carried on the ship. This involved the concatenation of 1 hour image files to 6 hour netCDF files (see details in GLORIA Image Processing Handbook prepared by the authors and provided to the Marine Institute). Due to the large volume of data, the surveyed area was subdivided into map areas measuring 2º x 2º for later detailed processing. For each map area the following procedures had to be completed:

- ✓ Merging navigation data and geographic positioning
- ✓ Geographic registration of each pixel of the sonar image
- ✓ Heading correction
- ✓ Slant range correction
- ✓ Shading correction
- ✓ Filtering (essential band pass filtering) to remove noise and artefacts

- ✓ Output was written to LANDSAT format files

The files produced from this process were imported into Erdas Imagine in which mosaicing of the image takes place. The image consists of a number of layers, the number of which is related to the maximum deviation of the ship's course. The aim of mosaicing was to consolidate all the layers into a single layer containing the most relevant information. In each layer, polygons were drawn manually to enclose the Areas Of Interest (AOI) i.e. the area in that layer which was to be kept. During mosaicing each of the AOI's were extracted from the respective layers and merged to form a new image (a different file) consisting of a single layer. The combined individual map mosaics were joined to produce a single mosaic of the entire survey area. A summary of the processing methodology is shown in Figure 4.

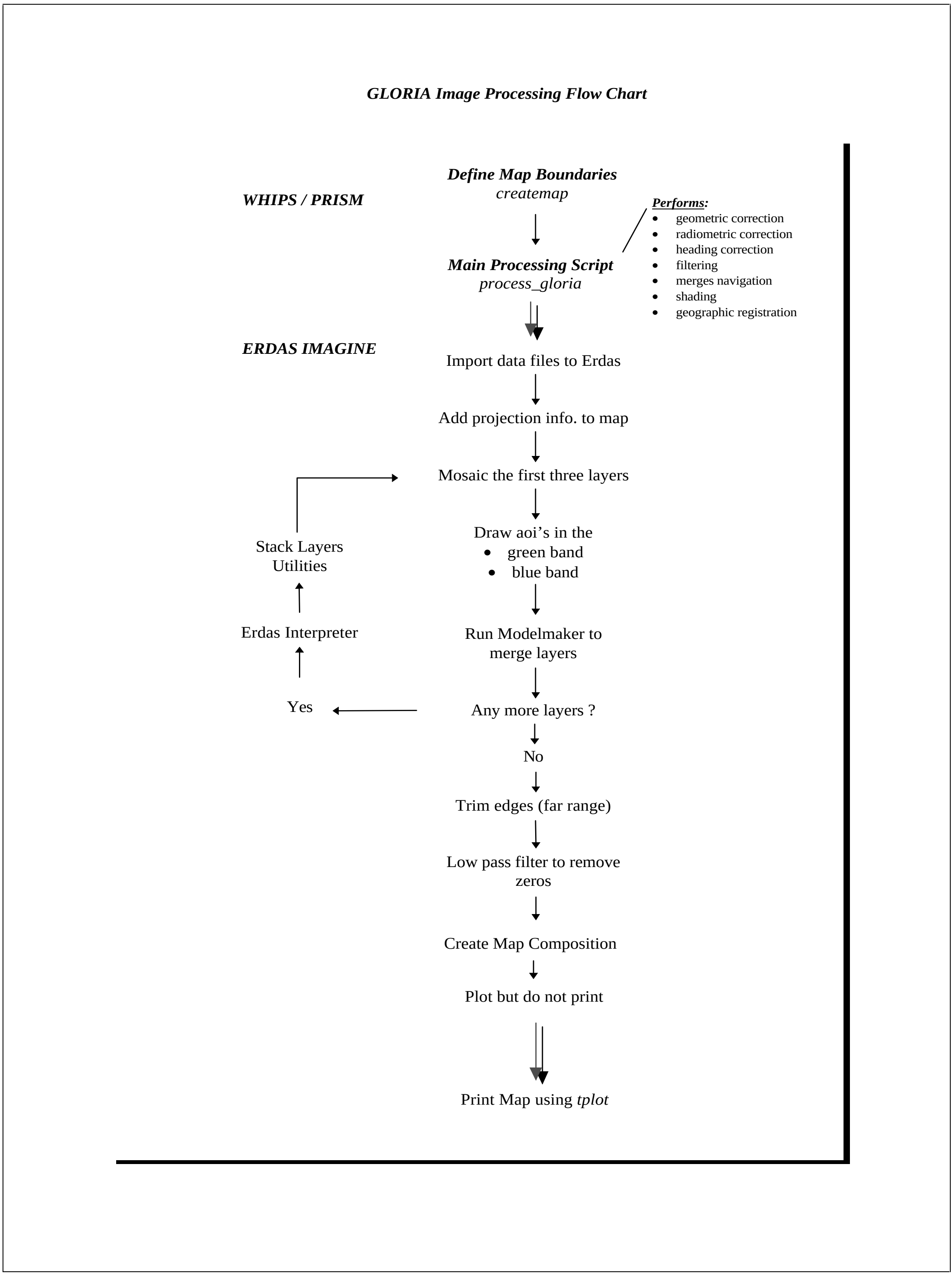

Figure 4: GLORIA Image Processing flow chart.

Digitising and Processing Old GLORIA Data

In addition to the AIRS96 image processing, older GLORIA data from RRS Discovery cruise 84 and RRS Discovery cruise 123 (see Figure 5 for survey track lines) were digitised and edited. Data from the old magnetic tapes relevant to the area of interest (Rockall Trough and Porcupine Seabight) were digitally recorded in PC netCDF format. Each of the files was edited to ensure the time tick-marks on the image corresponded to the start and end times in the cruise log-book. Depending on the GLORIA coverage, the nadir area (region directly below the ship's tracks where there is no sidescan sonar coverage) in the image contained data, which belonged to the far range. This was wrapped onto the outer margins of the image to give a complete sonar image. Details of the procedure are documented in the GLORIA Image Processing Handbook prepared by the authors and provided to the Marine Institute.

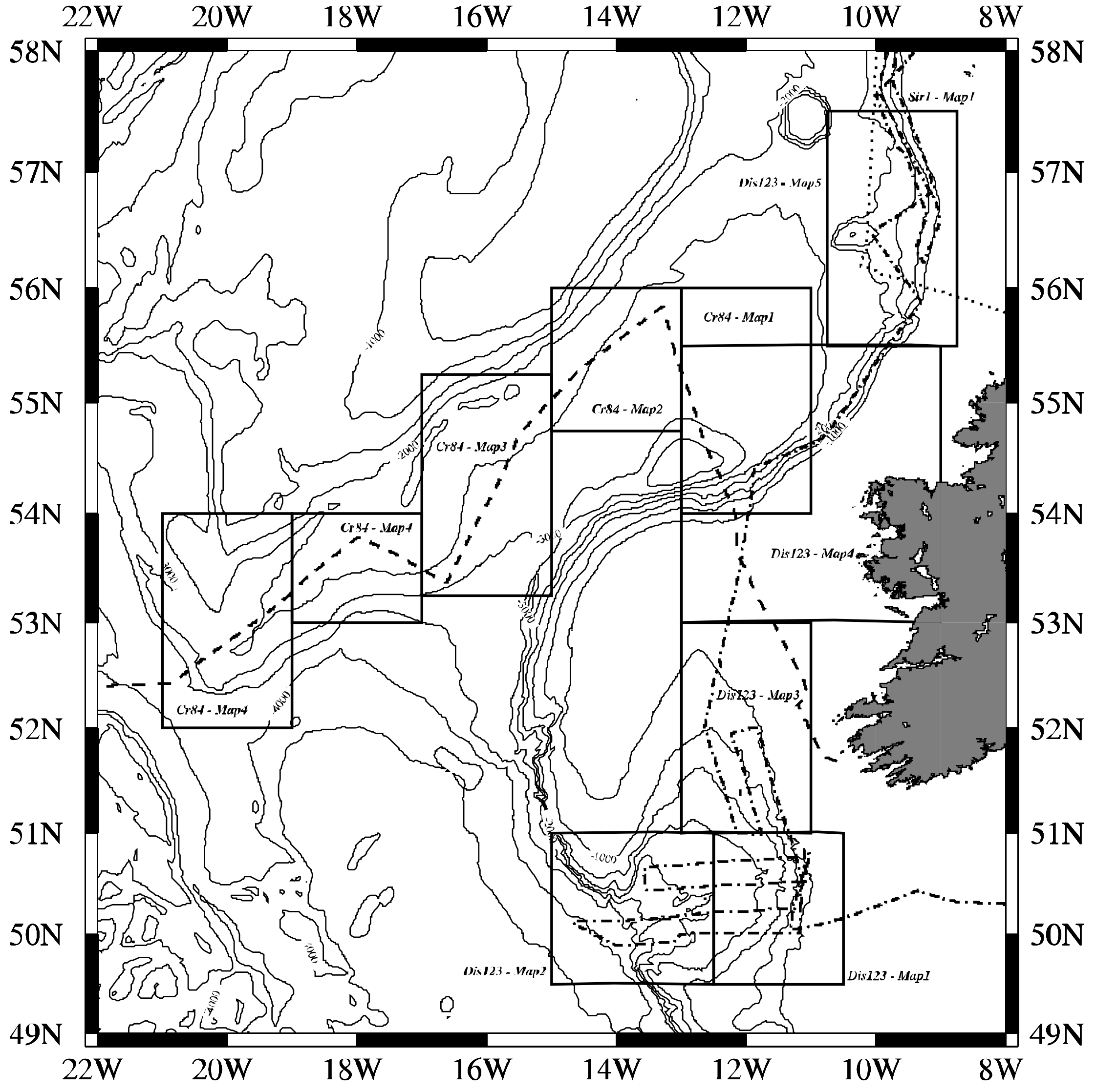

Figure 5: RRS Discovery Cruise 123 (dash-dot-dashed lines) and RRS Discovery Cruise 84 (dashed lines) tracks. The rectangles represent 2º x 2º map areas used to process the data.

(3) A low to very low, monotonous, homogeneous backscatter pattern (dark grey to black tones) is caused by absorption of the acoustic pulse by thick, unconsolidated hemipelagic muds and biogenic oozes.

Combining sidescan sonar characteristics, 3.5 kHz profiler data and other track-line information, four broad geomorphologic domains can be distinguished: (a) canyons, channels and fan systems, (b) slumps, slides and debris flows, (c) contourite and drift-related deposits, and (d) carbonate mounds.

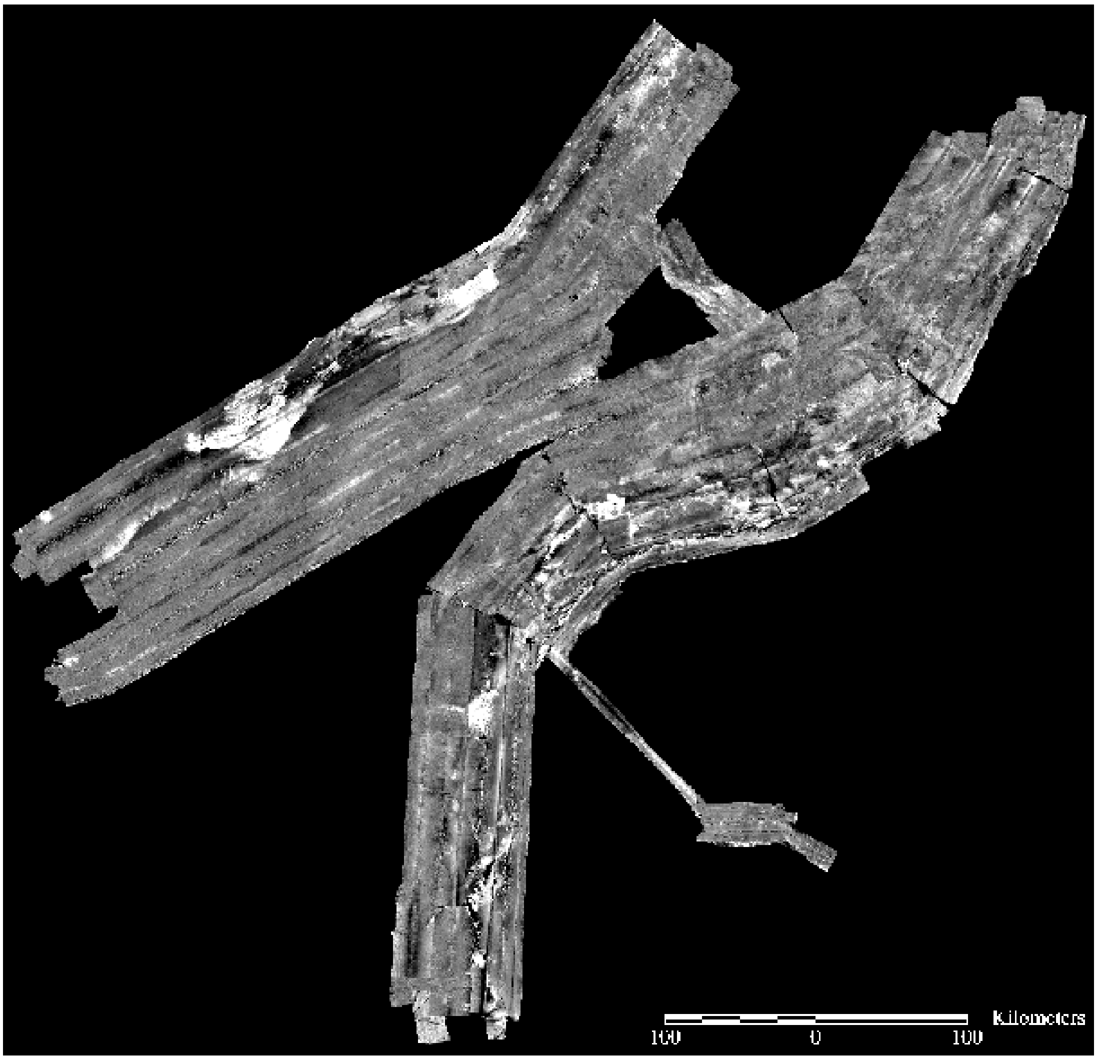

Figure 8: GLORIA sonar mosaic of the AIRS96 cruise.

Canyons & Channels

On the GLORIA mosaics a series of dramatic canyon systems are imaged across the upper and mid slope of the eastern margin of the Rockall Trough, where they are the most pronounced feature on the slope. They are absent from the western margin of the Rockall Trough. On the eastern margin, they appear as linear to curved features with associated high and low backscatter. In profile, they have steeply incised walls and flat floors. A thin (5-15 m) layer of sediments covers the canyon floors. The occurrence of canyons increases from the south-eastern margin to the northeast, with the most occurrences along the northern margin of the Porcupine Bank (see Figure 9).

Spatial variation in the density of these features is also accompanied by changes in canyon morphology. Canyons in the southeast are predominately oblique to the basin margin. The most spectacular system occurs on the western flank of the Porcupine Bank (see Figure 10). This canyon complex is 20 km wide and extends for approximately 70 km from the shelf edge to the basin floor. The canyon originates in 500-700 m water depth on the upper slope and consists of two broad (20 km wide) canyon heads, which open individually into NE-SW trending canyons. The canyon walls and the inter-canyon areas appear as high backscattering targets on GLORIA, while the canyon floor exhibit low to medium backscattering. In profile, the canyons are U-shaped, flat-floored and steep-walled. Gradients along the walls exceed 20°. Downslope they merge at a water depth of 2,000 m to form a single, low sinuosity, poorly backscattering channel. Subtle variations within the predominantly low backscattering region near the canyon mouth suggest the presence of a lobate fan measuring 45-60 km long and 25 km wide.

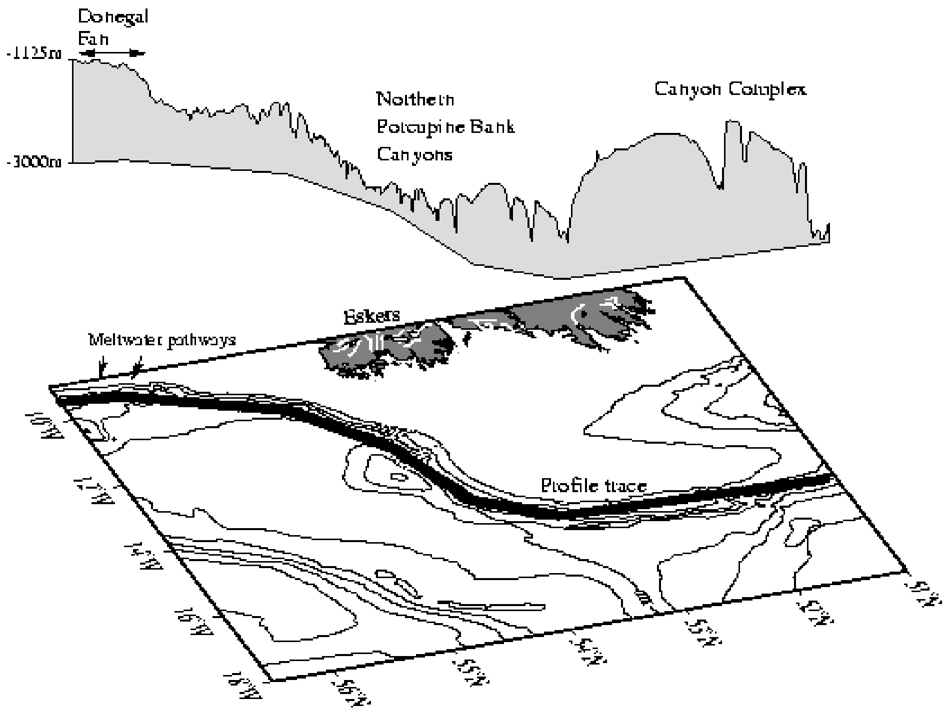

Figure 9: Depth profile (thick dark line) extracted from the 3.5 kHz echosounder data. This profile highlights the increase in frequency of canyon incision as one follows the profile from the southeast to the northeast. Along the southern margin of the Rockall Trough there are few large canyons while along the eastern and northeastern margin there are numerous small canyon incisions.

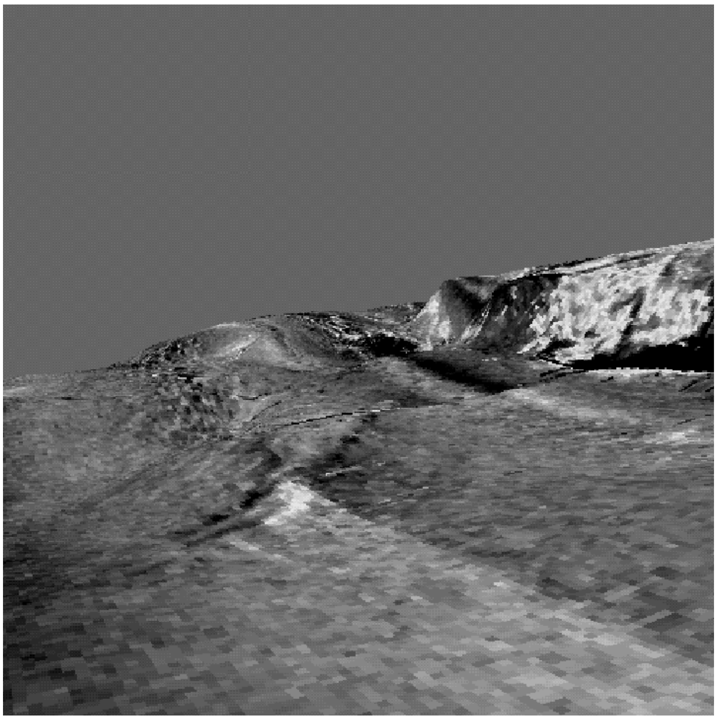

Figure 10: 3-D perspective view of the Porcupine Bank Canyon, southeastern Rockall Trough. The GLORIA sonar mosaic has been draped on regional bathymetry to create this image.

Deep-sea canyons, similar to their terrestrial counterparts, are formed by deep incisions into the country rock. Channels are low relief (low height to width ratio), depositional features generally formed in regions of moderate to low relief i.e. base of slope, or shelf margin. Channels are observed along the east-west and northeastern-southwestern trending margin segments of the eastern Rockall Trough. They are not as frequent as the canyon systems. These are generally small (i.e. 5-10 m deep and 20-100 m wide) bordering the maximum resolution of both the 3.5 kHz profiler (see Figure 11) and sonar records. The channels to the north of the Porcupine Bank (55ºN, 12º30'W) are observed on the sonar records as a series of curved tributaries coalescing downslope to form a single, discontinuous channel 10 km long and *c.* 100 m wide.

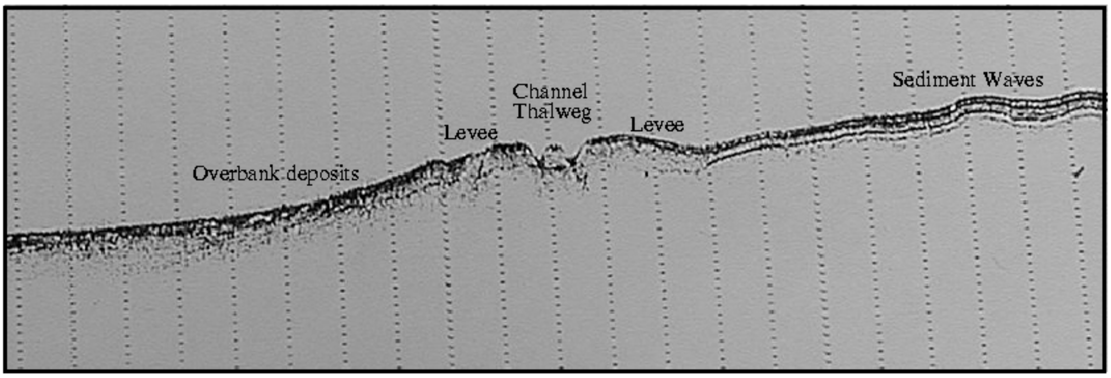

Figure 11: 3.5 kHz profile across a channel on the eastern margin of the Rockall Trough. This profile represents 40 km along the sea floor and the vertical dashes represent a height of 5 m.

In the southern Porcupine Basin, GLORIA data from the Discovery Cruise 123 (1984) mapped the Gollum Channel System. The Gollum Channels are long, low sinuosity, terraced, flat-bottomed, east-west trending channels, typically 100-280 m deep, 1-5 km wide and 100 km long in the southern Porcupine Seabight (see Figure 12). This channel system spans 200 km, trending east-west from the eastern margin of the Porcupine Seabight to the Seabight mouth and the Porcupine Abyssal Plain. Water depths vary from 200 m in the east to 3,500 m in the distal sections of the Gollum Channel System. The five major tributaries of this channel system coalsce in the south-central part of the Porcupine Basin to form a single channel which exits at the mouth of the Porcupine Seabight. The southern channel is highly sinuous and discontinuous. The poor backscattering intensity suggests that it is inactive. In contrast, varying backscatter strength in the axes of the northern channels suggests active transport of sediments through these channels. The average slope along the central region of the Gollum Channel System is 1º.

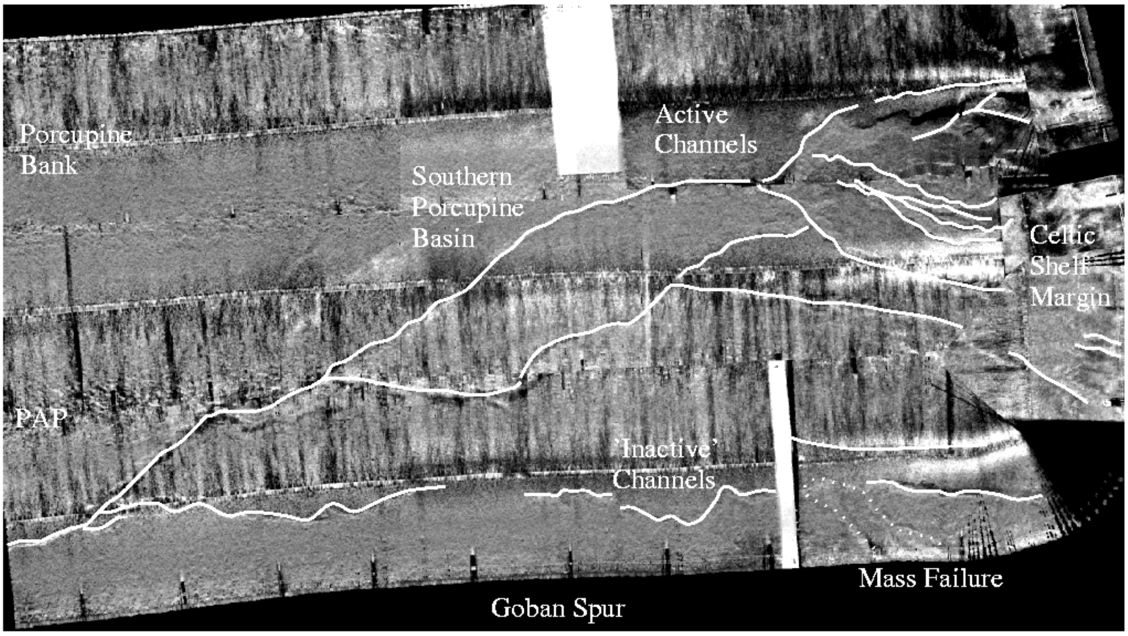

Figure 12: GLORIA sidescan sonar mosaic from the Gollum Channels, southern Porcupine Seabight. The Gollum Channels span 200 km from the Celtic shelf margin in the east to the Porcupine Abyssal Plain to the west. Southampton Oceanography Centre is acknowledged for the acquisition of this dataset. The authors (re) digitised and processed this extensive sonar image dataset.

Slumps, slides and debris flows

GLORIA sidescan sonar images from the NW margin of Rockall Trough show clear evidence for large-scale downslope gravitational sediment movement. The AIRS96 survey imaged the mid- to lower slope of the Rockall Bank Mass Flow (see Figure 13). The mid-slope region is characterised by a low backscattering arcuate ridge. Further downslope from the ridge, an area of mottled, high, saturated backscatter pattern with large, 1-2 km diameter blocks, aligned parallel to the bathymetric contours is thought to represent the debris flow stage of this mass wasting feature. Fine, streaky, low to medium backscatter patterns on the basin floor reflect the turbidity flow deposits possibly related to the slumping and sliding events on the upper slopes of the margin. To the north 3.5 kHz profiles across the debris and turbidity flow deposits show that large lateral scarps, in excess of 20 m high, truncate a sediment wave field associated with the northward continuation of the Feni Sediment Drift (see Figure 14). The scarps are less pronounced along the southern margin of the failed slope margin.

The deposits of turbidity currents downslope from the failures extend to at least 100 km from the base of slope. The total volume of sediment estimated to be re-deposited is in the order of 3,000 km^3. The presence of two stacked, lobate backscatter structures on the basin floor suggests that there were probably two major flow episodes. Two channel-like features within the turbidite flow region indicate that the flow was probably confined through two funnel-shaped entrant zones. These zones are partially filled with sediments, indicating that smaller flows, pelagic sedimentation and strong bottom currents are reworking the turbidite deposits.

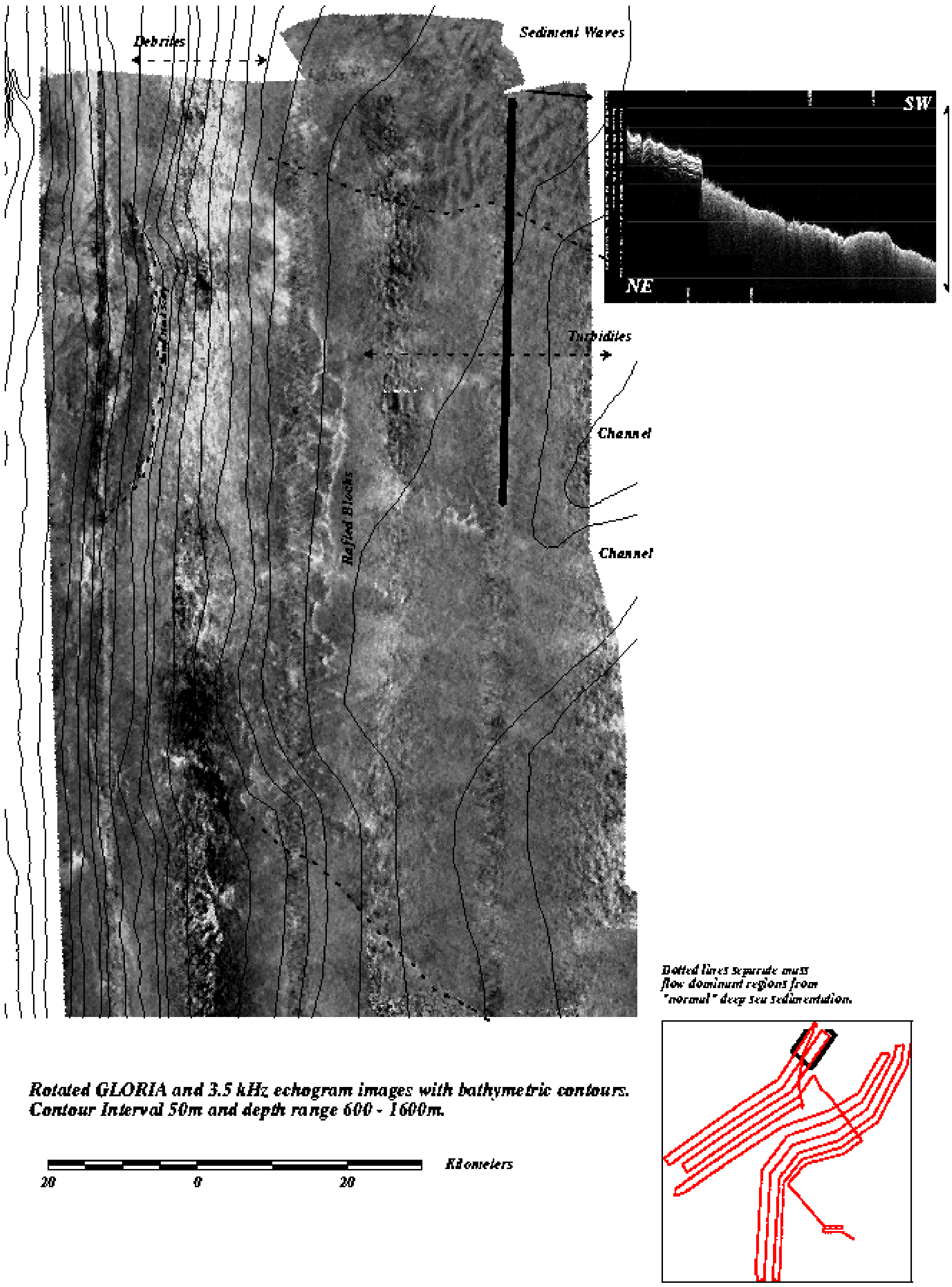

Figure 13: Sonar mosaic image of the Rockall Bank Mass Flow. The AIRS96 cruise imaged the mid-slope area of this mass flow. The primary slide scar is present on the shelf break (to the west of image). Note the large-scale nature of the feature. The flow affected at least 100 km of the margin and basin floor of the Rockall Trough.

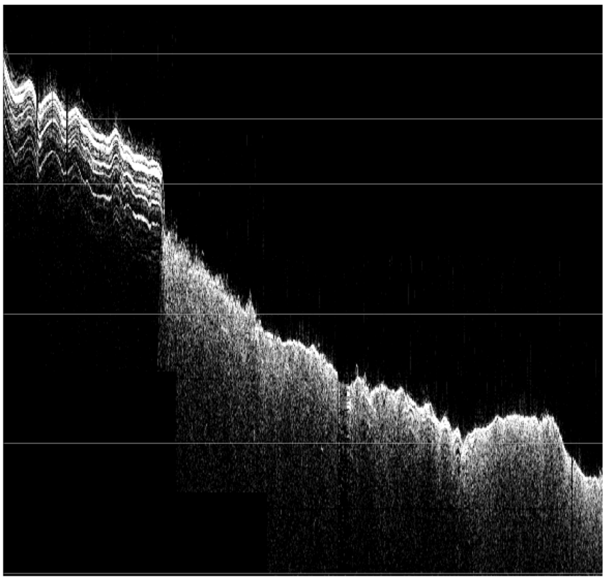

Figure 14: Enlarged section of the 3.5 kHz profile across the northern margin of the Rockall Bank Mass flow (see previous figure). The Rockall Bank Mass Flow has cut through a sediment wave field to the north, leaving a scarp of 20m. The total area effected by the Mass Flow exceeds 12,000 km^2.

A wide spectrum of slope failure features occurs along the eastern margin of the Rockall Trough. Cuspate to linear, NE-SW trending, approximately slope-parallel failure scars incise the upper slope of the eastern margin (see Figure 15). The GLORIA images resolve these failure zones as narrow curvilinear belts of high reflectivity. They are typically 2-8 km long and represent downslope displacements of *c.*100-2,000 m. These failures produce a progressive downstepping of the margin. They define a general area of collapse along a large section of the slope (about 100 km long) which is attributed to the steep and unstable nature of this part of the margin.

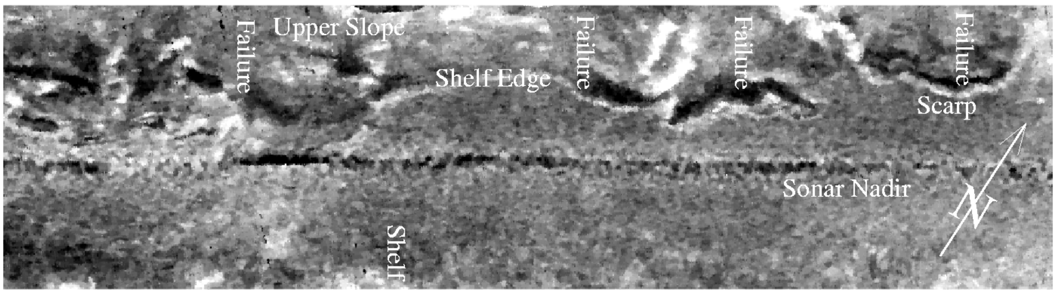

Figure 15: GLORIA mosaic highlighting listric slide scars on the shelf break along the eastern margin of the Rockall Trough. The scars are 2-6km long. The central line in the image is a sonar artefact.

Along the southeastern margin, an area covering over 600 km^2 (53ºN, 15.5ºW), characterised by saturated levels of bright backscatter, is interpreted as a mass failure feature. This feature occupies the mid- to lower slope region and is characterised by slumping and debris flows on the mid-slope and turbidite deposits on basin floor.

A range of smaller slope failure features is concentrated on the middle slope region along the northern margin of the Porcupine Bank. A submarine slide, identified by a "scallop" shaped failure scar, shows a general SE-NW transport direction. Coherent mass movement features are defined by a series of bright backscattering ridges, and probably represent extensional tensional gashes. In addition, along the mid slope region, areas of high reflectivity (typically 50 km long and 5 km wide) with oval shaped poorly backscattering spots (1 km diameter) probably represent consolidated strata exhumed by multiple failure events.

Feni Sediment Drift

The most prominent sedimentary feature, covering the central and western parts of the Rockall Trough basin floor, is a giant elongate, mounded sediment drift: the Feni Sediment Drift. This is the oldest and one of the largest sediment drifts in the NE Atlantic. It is a sinuous, NE-SW oriented axial ridge with dips along the flanks ranging from 0.5 - 1º and is characterised by elevated topography. The surface of the drift is covered with large sediment waves, with dominant slope sub-parallel crests 2-20 km long and 0.5-4 km wavelength. The amplitude of these waves varies between 20 m and 60 m.

On sonar records these sediment waves appear as faint linear backscatter features towards the far range of the sonar swath. GLORIA data from AIRS96 (see Figure 16) shows that wave trends are dominantly parallel to the regional slope. A diffuse zone of high backscatter about 100 km in length represents the main axis of the drift. The overall low backscatter intensity and lack of features is mainly due to the absence of significant relief and the thick, fine-grained nature of the basin floor sediments. Pelagic ooze, calcareous muds and terrigenous silts of the Feni Drift have a low micro-scale roughness and acoustic impedance necessary for enhanced backscatter levels.

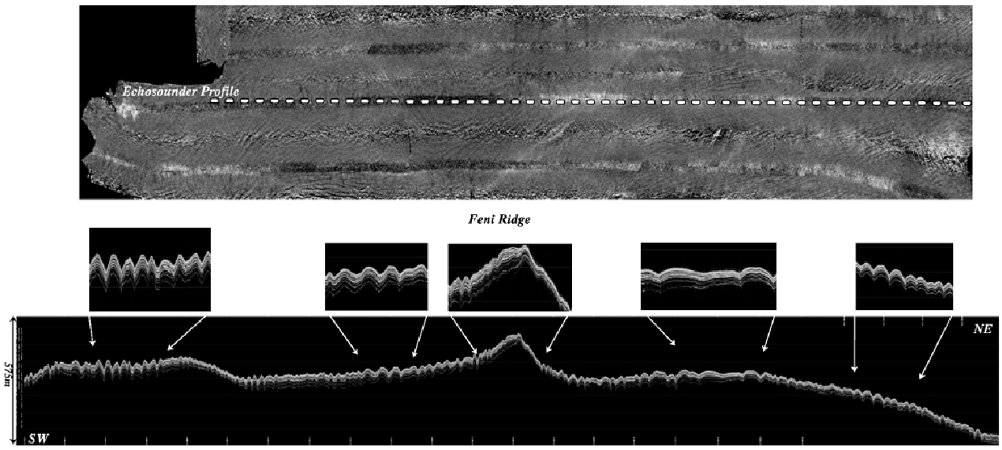

Figure 16: GLORIA sonar images and 3.5 kHz profile of the Feni Sediment Drift. The sonar mosaic (uppermost image) highlights the poor backscattering nature of the region. This is consistent with sonar images from regions with thick, unconsolidated soft sediments. The 600 km profile (lowermost image) highlights the changes in size and geometry of the sediment waves associated with the Feni Sediment Drift.

On the echosounder profiles, the sediment waves have an symmetrical to asymmetric fold like geometry with broad, single, gently rolling hyperbolae with a sharp bottom echo and continuous and conformable sub-bottom echoes. The symmetry of the sediment waves changes from symmetric away from the ridge axes to asymmetric closer to the axes. This asymmetry may reflect preferential deposition on the upstream/upslope wave flank. As wave migration ceased about 2.4 Ma, sediment loading, compaction and gravitational creep are likely causative mechanisms for the present day wave asymmetry.

Carbonate Mounds

The Hovland mounds (named after the Peter Hovland, lead author of the pioneering paper Hovland *et al.* 1994 on the mud mounds) were recorded on the AIRS96 survey and are conical in shape. They stand 50 - 250 m high and are in the range of 50 - 3000 m wide. They lie in water depths ranging between 750 m and 1,000 m in the northern part of the Porcupine Seabight. A total of 31 separate mounds are aligned in an E-W direction, with the largest mounds in the south. The size and frequency of these mounds decreases towards the north (see Figure 17). In plan view, these mounds are oval to round in shape, and appear to have a circular depression or "moat" around them.

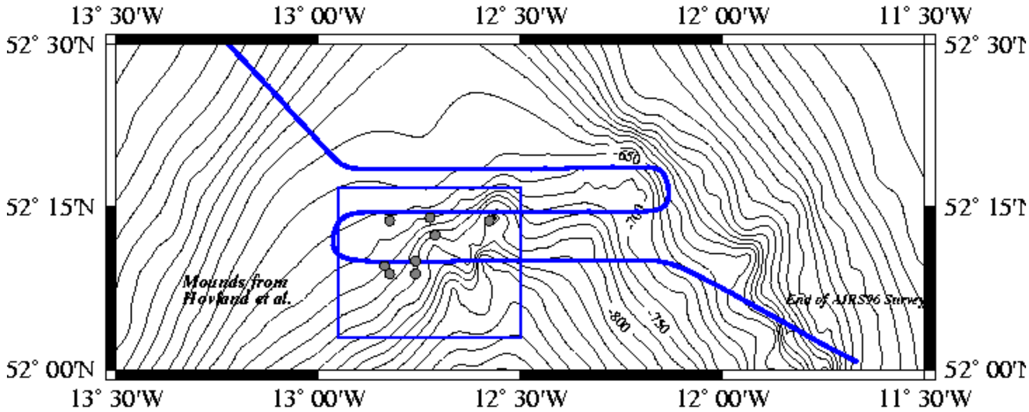

Figure 17: Location of the large Hovland Mounds imaged by the AIRS96 cruise in the northern part of the Porcupine Seabight. See Hovland *et al.* (1994).

On GLORIA sidescan sonar records, these mounds are imaged as “pimple” shaped artefacts on a relatively smooth, homogeneous, medium backscattering background (see Figure 18). The slight decrease in backscattering intensity around the mounds, suggests a subtle change in seabed morphology or sediment type. The height of these mounds, based on the length of their shadow, varies between 50 - 500 m. The mounds covers on average 0.64 km^2 and appear to be aligned in an E-W orientation. Variation in backscatter strength in the vicinity of the mounds forming wispy or streaky lineation is indicative of strong currents transporting sediment around the mounds. Further indications for strong currents in the region come from the GLORIA data obtained on the Discovery Cruise 123, in 1981, on the basis of which “blind” channels and dune-sized sand waves were identified. The N-S orientation of these features suggests a poleward flowing current along the eastern margin of the Porcupine Seabight.

The AIRS96 cruise traversed two Hovland mounds. The 3.5 kHz echosounder profiles highlight the conical shape of the mounds and emphasise the presence of a moat around the mounds. There is little or no acoustic penetration and the prolonged sub-bottom echo is characteristic of “hard” acoustic targets.

Raw Sidescan Images from the Porcupine

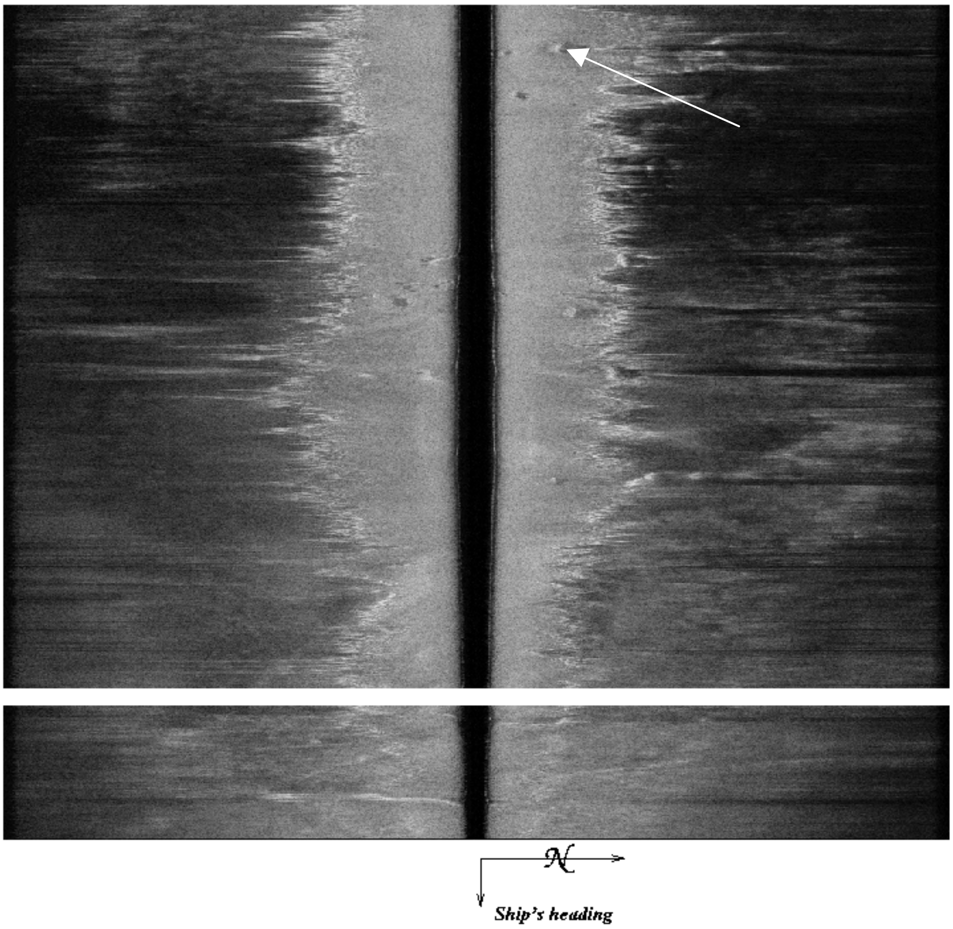

Figure 18: Raw, unprocessed sidescan sonar imagery from the AIRS96 cruise (see previous figure for location), clearly showing the "pimple" shaped carbonate mounds against the backdrop of a texturally homogenous and smooth seafloor (arrow points to only one example).

The Belgica mounds (named after the ship that investigated these features during a scientific cruise in the summer of 1997, Henriet *et al.* 1998) are relatively small, elongate, NW-SE trending echelon mound complexes forming a singular ridge with sediments trapped or ponded on the shallower side of the mounds. GLORIA sidescan records from the Discovery Cruise 123, in 1981, imaged the Belgica mounds as a poorly backscattering ridge, aligned parallel to the bathymetric contours. This ridge is 8 km long and 500 - 1000 m wide. Based on the low backscatter intensity, this ridge possibly represents sediments ponded on the landward side of the mounds.

Winnowed pebble lag

South of the debris flows on NW Rockall Trough, along the mid to upper slope of the Rockall Bank, an area of very high backscatter (white to light grey hues) is observed on the sidescan sonar images (see Figure 19). On the 3.5 kHz echograms, continuous, sharp and prolonged bottom echoes with no sub-bottom and irregular relief indicates the presence of a hard, rough surface covered only by a intermittent, thin veneer of unconsolidated sediments. Although, nearly all detailed structure is obscured by the saturated high backscatter patches, convoluted ridges on the upper to middle slope are suggestive of sediment failure. Further downslope, linear high- and low backscatter ridges parallel to the bathymetric contours are also indicative of sliding and slumping. In the absence of geological samples and high-resolution seismic data, the origin of this bright backscatter region is speculative. Outcropping basement, consolidated sedimentary strata or a winnowed glacial pebble/gravel lag deposit are the most likely causative agents responsible for the high acoustic response. Conventional seismic data from this region do not support the interpretation of basement at or near the seabed. The reflectors are coherent, laterally continuous and indicate the presence of thick sediment cover. A recent sidescan sonar and shallow bottom sampling survey along the north-western margin of this region (Kenyon *et al.* 1998) showed evidence for strong currents and the active transport of coarse sandy material. In addition, Flandrian beach conglomerates were identified in water depths of 200 m along the margins of Rockall Bank. Hence, based on the limited regional studies and acoustic characteristics, the bright backscattering region imaged on the GLORIA records is likely to be caused by coarse, current winnowed sediment field such as glacial gravel or pebble lags.

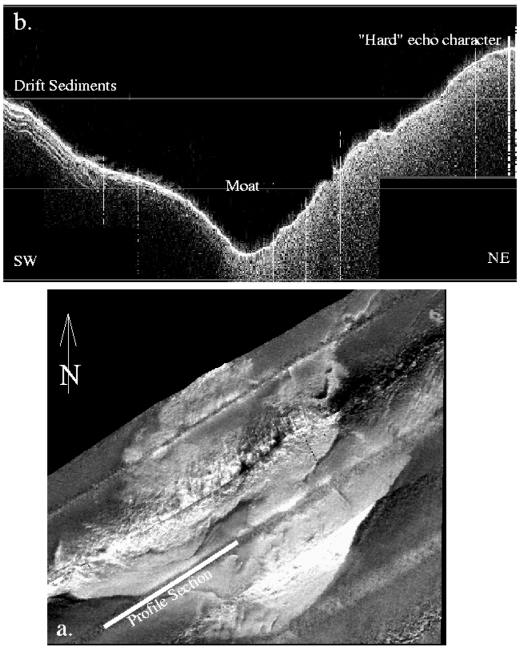

Figure 19: (a) Sonar mosaic of the high backscatter patch (~6,000 km^2) along the western margin of the Rockall Trough. (b) Echo profile across the southern margin of the winnowed pebble lag highlighting the distinct moat separating the Feni Sediment Drift from the lag region.

FURTHER ANALYSIS

In addition to processing and interpretation of the AIRS96 sonar and echosounder data numerous techniques were applied to the data set. The aim of this exercise was to find clues that might provide a useful insight into the formation, age and cause of the various sedimentary features observed in sonar and echosounder data. Three of these techniques are highlighted below. Details have been excluded for the sake of clarity and brevity.

Gradient Analysis

Geomorphological characterisation into slope, shelf, continental rise are based on changes in gradient and water depth. In the case of GLORIA sonar images, gradients are an important factor controlling the intensity of backscatter. Hence it is important to grasp the extent of morphological variability in the Rockall Trough.

Gradient analysis is the study of relative changes of bathymetry. The GEBCO97 ASCII dataset was used to generate a Digital Elevation Model (DEM) and generate shaded relief images (aspect images) of the study area. Results from the gradient analysis are shown in Figure 20. The map highlights the slopes of both the eastern and western margins of the Rockall Trough. Prominent features on the basin floor include the southern and eastern margin of the Feni Sediment Drift, the Hebrides Terrace Seamount and Anton Dohrn Seamount. The average gradient for the study area is 6º with maximum values of 22º along the southeastern margins of the Rockall Trough and around the seamounts in the northern Rockall Trough.

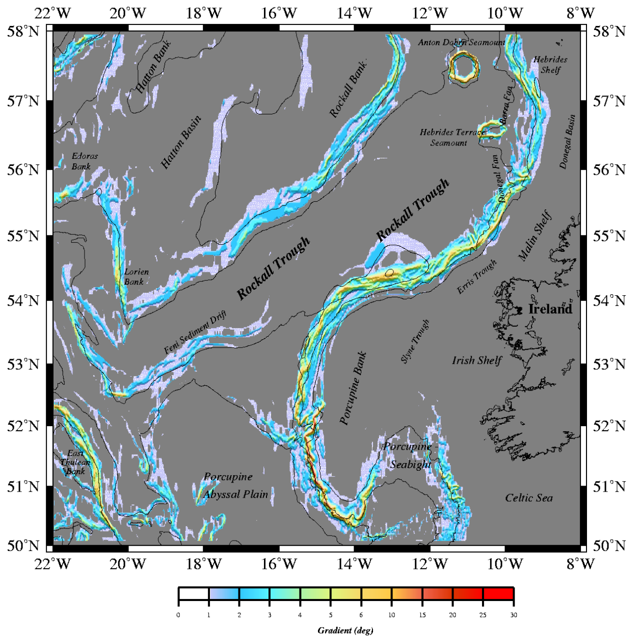

Figure 20: Gradient analysis results from the AIRS96 study area. Note the difference in gradients along the eastern and western margin of the Rockall Trough. The average slope along the eastern margin is 6º, while it is 3.5º for the western margin.

Other features on the slope map include the steeper southern and eastern margin of the Feni Drift. The average gradient along this margin of the Feni Drift is 1º. The western and northern margin of the sediment drift does not have a significant variation in gradient. It is remarkable that soft sediments such as those deposited on the Feni Drift remain stable at 1º. Another curious feature on the slope map is the apparent "hole" to the north of Porcupine Bank. This hole represents a deepening at the northern margin of Porcupine Bank. The gradients along the margin of this large depression exceed 1º.

Factor of Safety Analysis

Theoretically, sediments on slopes less than the angle of internal friction (30º) are stable, assuming normal consolidation and the sediment column is not subject to external forces other than gravity. Excluding gravity, the triggers that initiate mass movement are either episodic such as earthquake induced shaking, or cyclic as in the case of wave loading. The basic condition for any slope failure to occur is when the stresses on the sediment exceed its strength. Stress increase or strength reduction, or a combination of the two, would be sufficient to initiate downslope movement. Stress may be increased or reduced by a wide variety of processes, which include crustal tectonics, earthquake loading, current scour, surface waves or cyclic loading. Sediment strength is variable and is increased or reduced by sedimentary loading, cyclic loading by waves, pore gas generation and tidal water level changes. Analysis of the conditions that cause submarine slopes to fail is a difficult task mainly due to the inaccessibility of the slopes and lack of precise sediment strength data.

Factor of safety (FOS) analysis with respect to earthquake shaking was conducted using the results from the slope analysis mentioned in the previous point. Factor of Safety (FOS) is the ratio of undrained shearing strength to effective overburden stress. Horizontal acceleration, pore pressure ratio and sliding depth are taken into account to evaluate the probability of failure (F). If F is equal or less than 1, the slope is unstable and failure will occur.

Shear strength parameters, horizontal acceleration (\% g) and the sliding depth values were altered to test failure criteria for the southeastern Rockall Trough region. Using the present day slopes from the southeastern margin of the Rockall Trough, the analysis to calculate the Factor of Safety was performed using (a) varying strength, (b) varying acceleration, and (c) varying the sliding depth. The results are highlighted in Figure 21. The green colours represent regions of the slope with factor of safety greater than 1, implying stable slopes. Decreasing the shear strength parameter uniformly destabilises the entire region. The analysis predicts that the slope region is stable under normal conditions. Shallow sliding accompanied by low shear strength would be the most likely cause of sediment failure in the Rockall Trough. Relatively large earthquake shaking events may also trigger instability, especially along the southeastern margins of the Rockall Trough.

Summary of results

The AIRS96 GLORIA sidescan sonar survey has allowed definitive identification and accurate mapping of a variety of mass movement structures and depositional sedimentary structures along the margins of the Rockall Trough (see Figure 23.)

1. Sidescan sonar mapping reveals a large variety of sedimentary processes active at various scales. The Feni Drift dominates the south-western margin and central parts of the Rockall Trough. It forms a 600 km long, 300-800 m thick, mounded, broadly NE-SW trending, sediment ridge covered by regular, symmetric, large-scale sediment waves. The morphology and structure of the Feni Sediment Drift reflects the presence of intense counter clockwise currents active in the Rockall Trough.

2. The north-western margin of the Rockall Trough contains a series of large-scale, elongate, 150 km long debris flows with rafted blocks up to 2 km in size.

3. In contrast to the western margin, canyon systems dominate the physiography of the eastern margin. Highly incised canyons, listric slump scars and slides characterise the steep south-eastern flanks of the Rockall Basin. The degree and frequency of canyon incision increases along the northern Porcupine Bank and NE Rockall Trough, reflecting increase in sediment supply and possible glacial influence on the basin margin.

4. A number of carbonate mounds were imaged in the Porcupine Seabight.

5. No reliable swath bathymetry data was obtained due to poor signal to noise ratio. Biological noise, water stratification and/or soft sea bed are some of the likely reasons for the poor bathymetry data quality.

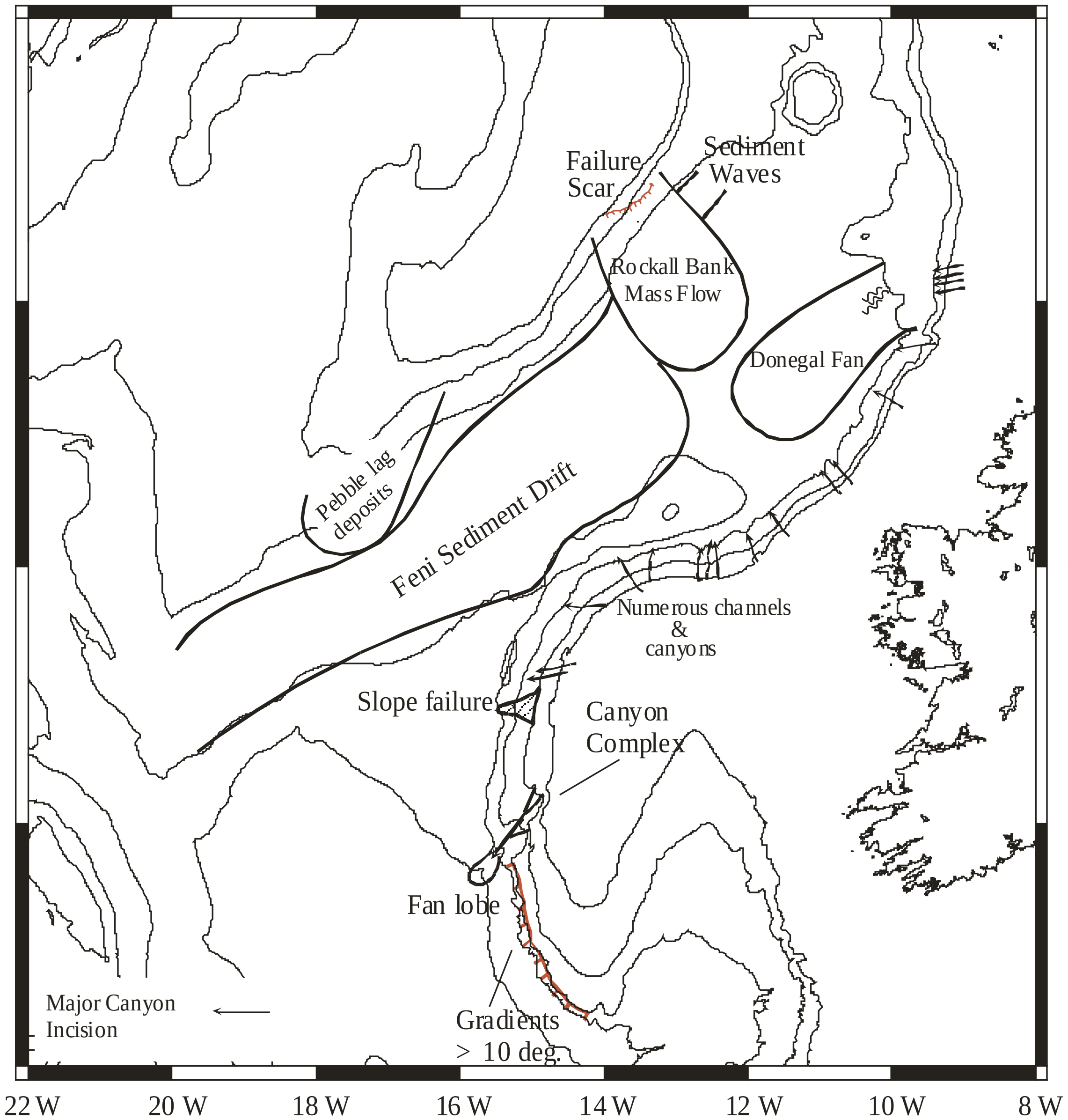

Figure 23: Summary of main features observed from the AIRS96 data in the Rockall Trough. This map highlights large-scale (excess of 50 km) features identified using the AIRS96 data.

CONCLUSIONS

The GLORIA sidescan sonar images obtained in the AIRS96 survey provide a first step towards an integrated study of the Irish Margins. The survey, in addition to generating an awareness of the great potential of the Irish marine resources, offers a number of practical applications, such as locating and assessing sites for drilling, laying pipe lines, and cables. The oceanographic and seabed data will aid fisheries research and the data gathered will make a valuable contribution to the study of oceanography, sedimentology, and geomorphology in the region including newly discovered cold water coral reefs (Costello 1998). As a result of the AIRS96 survey, there is a renewed interest in the Irish Marine resources, as evident from the formal announcement in 1999 of a seven year indepth survey of the Irish Continental Shelf to be co-ordinated by the GSI and the Marine Institute. The survey has paved the way for a number of EU-funded marine research in the region with significant Irish participation. These include ACES, ECOMOUND, GEOMOUND and STRATAGEM. In addition, and of equal importance, is the fact that the project has facilitated high level training of scientific personnel, and the establishment of a core of expertise in the acquisition, processing and interpretation of large scale sidescan and other marine geoscience projects.

The GLORIA mosaics from the AIRS96 survey in the Rockall Trough provide information and constraints on a wide range of erosional and depositional features. The key scientific findings are:

(1) The survey highlights the contrast in sedimentary features along the eastern and western margin of the Rockall Trough. A combination of canyons, channels, sediment fans and mass wasting features dominate the eastern margin. The western margin is characterised by large-scale mass wasting and lacks evidence for significant canyon development and channelised sediment transport.

(2) Contour currents are responsible for reworking and deposition of sediments on the basin floor. The lack of prominent canyon mouth lobes and channels along the eastern margin attests to the strong erosive northern current along this margin. Sediments are re-deposited by southwestard flowing contour-hugging currents along the western margin.

(3) The spatial variability of features observed along the margins and basin floor of the Rockall Trough is caused by the interaction of downslope and alongslope processes. The increase of canyon frequency along the north-eastern margin of the Rockall Trough reflects increased sediment flux from the margins. Factors influencing these processes at longer time scales are likely to be basin subsidence, Quaternary glaciations and glacio-eustatic sea-level fluctuations.

(4) Although there are few constraints on the ages of these features, Tertiary uplift and Quaternary glaciations of the Irish margin are likely to have had a major impact on late Cenozoic sedimentary processes in the Rockall Trough.

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The scientific staff of the Southampton Oceanography Centre (UK) is thanked for their help during various stages of this project. In particular we wish to thank Neil Kenyon and Tim Le Bas for their continued help and support throughout the project.

Thanks are also due to all the members of the Steering Committee, and to the crew of the MV Siren for their contribution to this project

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APPENDIX 1

1. PROJECT DELIVERABLES

1. Vermeulen, N.J. (1997) *Hydrography, Surface Geology and Geomorphology of the Deep Water Sedimentary Basins to the West of Ireland*. Marine Resource Series, **2**, 41 pp. Marine Institute.

2. Unnithan, V., Shannon, P.M, McGrane, K, Jacob, A.W.B., Readman, P.W. & Keary, R (2000) Recon*naissance Survey of the Irish Continental Shelf/Shelf Edge (AIRS'96). Ma*rine Resource Series, No. 12 Marine Institute.

3. Two Ph.D. theses which are nearing completion will provide more detailed analysis and interpretation of the data.
   Unnithan – Geological and sedimentological analysis of sidescan sonar data in the Rockall Trough, west of Ireland.
   McGrane – Geophysical analysis and modelling of sidescan sonar image data from the Atlantic margin, west of Ireland.

4. GLORIA Image Processing Handbook. This handbook describes in detail both the acquisition and processing methodology adopted for the AIRS96 data.

5. A Quick Guide to GLORIA Processing. This guide is intended to aid the user during (re) processing the GLORIA data. It contains helpful tips and keywords needed to reprocess parts of the dataset.

6. 1 CD-ROM with raw and processed GLORIA data. This CD contains navigation and sonar imagery. See readme.doc on the CD for details on the content.

7. 1 CD-ROM with raw and processed GLORIA data from the Discovery Cruise 123 and Discovery Cruise 84. This CD contains navigation, sound velocity data and imagery data. The imagery data was recovered and re-digitised. A description of the files is provided on the CD.

8. 2 CD ROMs with raw and processing digital 3.5 kHz echosounder data. These Cds contain echosounder data from the part of the AIRS96 survey where digital data was available. No documentation is provided with the CD. See Handbook for details.

9. 45 CD-ROMs of raw bathymetry data from the AIRS96 survey. See handbook for details on the dataset.

Copies of the Reports 1 and 2 are available from the Marine Institute. For access to items 3 to 9 contact the Marine Data Centre, Marine Institute, UCD or DIAS.

APPENDIX 2

2. AIRS96 PUBLICATIONS

KEARY, R., JACOB, B & SHANNON, P., 1997. Reconnaissance Survey of the Irish Continental Shelf / Shelf Edge. Marine Institute Seminar, Dublin.

MCGRANE, K., READMAN, P.W., JACOB, A.W.B., UNNITHAN, V., SHANNON, P.M., KEARY, R. & KENYON, N., 1997. Recent slope instability features in the Rockall Trough, offshore Ireland. *UKGA-21, Abstracts of Lectures and Posters, Southampton*, 40.

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UNNITHAN, V., SHANNON, P.M., READMAN, P.W., MCGRANE, K., JACOB, A.W.B., KEARY, R. & KENYON, N., (in press). Slope instability and sediment re-distribution in the Rockall Trough: constraints from GLORIA. *In:* Shannon, P.M., Haughton, P.D.W. & Corcoran, D. (eds) *Petroleum Exploration of Ireland's Offshore Basins.* Geological Society, Special Publication.

VERMEULEN, N.J., 1997. Hydrography, Surface Geology and Geomorphology of the Deep Water Sedimentary Basins to the West of Ireland. *Marine Resources Series*, 2, 41.

APPENDIX 3

3. SCIENTIFIC MEETINGS AT WHICH THE RESULTS OF THE RECONNAISSANCE SURVEY OF THE IRISH CONTINENTAL SHELF/SHELF EDGE (AIRS'96) PROJECT WERE PRESENTED

International Meetings:

1. AGU - American Geophysical Union Fall Meeting (San Francisco, 1997, 1998, and 1999).

2. EGS - European Geophysical Society General Assembly (Vienna, 1997 and Nice, 1998).

3. EAPG - European Association of Petroleum Geoscientists (Geneva, 1997).

4. UKGA - United Kingdom Geophysical Assembly (Southampton, 1997).

5. ENAM II – European North Atlantic margins (Kinsale, 1997).

6. NEASP – North-East Atlantic Slope Processes (Southampton, 1999).

7. PEOIB – Petroleum Exploration of Ireland’s Offshore Basins (Dublin, 1999).

Local Meetings:

8. IGRM – Irish Geological Research Meetings – Belfast (1997), Galway (1998) and Dublin (1999).

9. UCD Postgraduate Seminar days (1997 and 1998).

10. Seminars in UCD, TCD and UCC, and presentations to oil companies.