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Shallow geology of the seabed in the vicinity of Orkney and the Sutherland coast.

Marine Geology and Geophysics Programme

Commissioned Report CR/12/078

BRITISH GEOLOGICAL SURVEY

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Foreword

BGS has carried out an investigation of the shallow geology of 6 sites in the vicinity of Orkney and the north coast of Scotland for Marine Scotland. Data collection was carried out using the Marine Scotland research vessel MRV Alba Na Mara by Simon Ritson and Dave Smith of BGS in collaboration with Peter Hayes of Marine Scotland. Data processing was carried out by Simon Ritson and Kirsten Crombie of BGS.

The cruise is logged as BGS project BGS 2012-2-MS.

Acknowledgements

In addition to the BGS staff acknowledged in the Foreword, Joe Bulat, Rhys Cooper, Dave Long and Nikki Smith have contributed to the production of this report. Kate Hemfrey provided multibeam data for the area north-west of Orkney. Figures 2, 5, 7, 12 and 14 contain Ordnance Survey data © Crown Copyright 2012.

Contents

Summary

BGS has used shallow seismic data to examine the shallow geology of 6 sites in the vicinity of Orkney and the north coast of Scotland for Marine Scotland. Three of the sites (Armadale, Costa Head and West of Mainland Orkney) are possible locations for renewable energy installations. In these sites, the most important factor is the depth of superficial deposits overlying bedrock or depth to rockhead.

Three other sites (Kyle of Tongue, Loch Eriboll and Scapa Flow) were surveyed during particularly poor weather when data collection in the main survey areas was not possible. The Scapa Flow site was surveyed because of its potential as a European Marine Energy Centre (EMEC) test facility for wave devices and in this area rockhead geometry is described. In the Kyle of Tongue and Loch Eriboll surveys, depth to rockhead appears to exceed 6 m throughout the areas and so the surface has not been mapped. The Loch Eriboll area displays a complex superficial geology with several phases of deposition. Combined with recently acquired multibeam data, this area will require detailed interpretation of the seismic sections which lies outwith the scope of this project.

1 Introduction

This survey was instigated by Marine Scotland, through an MOU agreement with the BGS, to allow collection of shallow marine geophysical data in areas identified by Marine Scotland. Eighty one seismic reflection lines were collected during the cruise, utilising the BGS Surface Tow Boomer and 7-channel hydrophone. The weather and sea state were typical for the time of year (February-March) with a prevailing large oceanic swell and high to very high winds influencing the quality of data collected. Details of the cruise and methods of data collection are described in Ritson and Smith (2012).

The primary survey areas are those that The Crown Estates have designated as of interest to renewable energy companies for the potential deployment of wind, tidal or wave energy generating devices.

For this survey there were three primary areas (Figure 1), Costa Head north-west of Orkney, West of Mainland Orkney (in the vicinity of Marwick Head and Mainland Orkney) and Armadale (off the north coast of Scotland). An additional site south-west of Shetland (Aegir) was not surveyed due to adverse weather conditions.

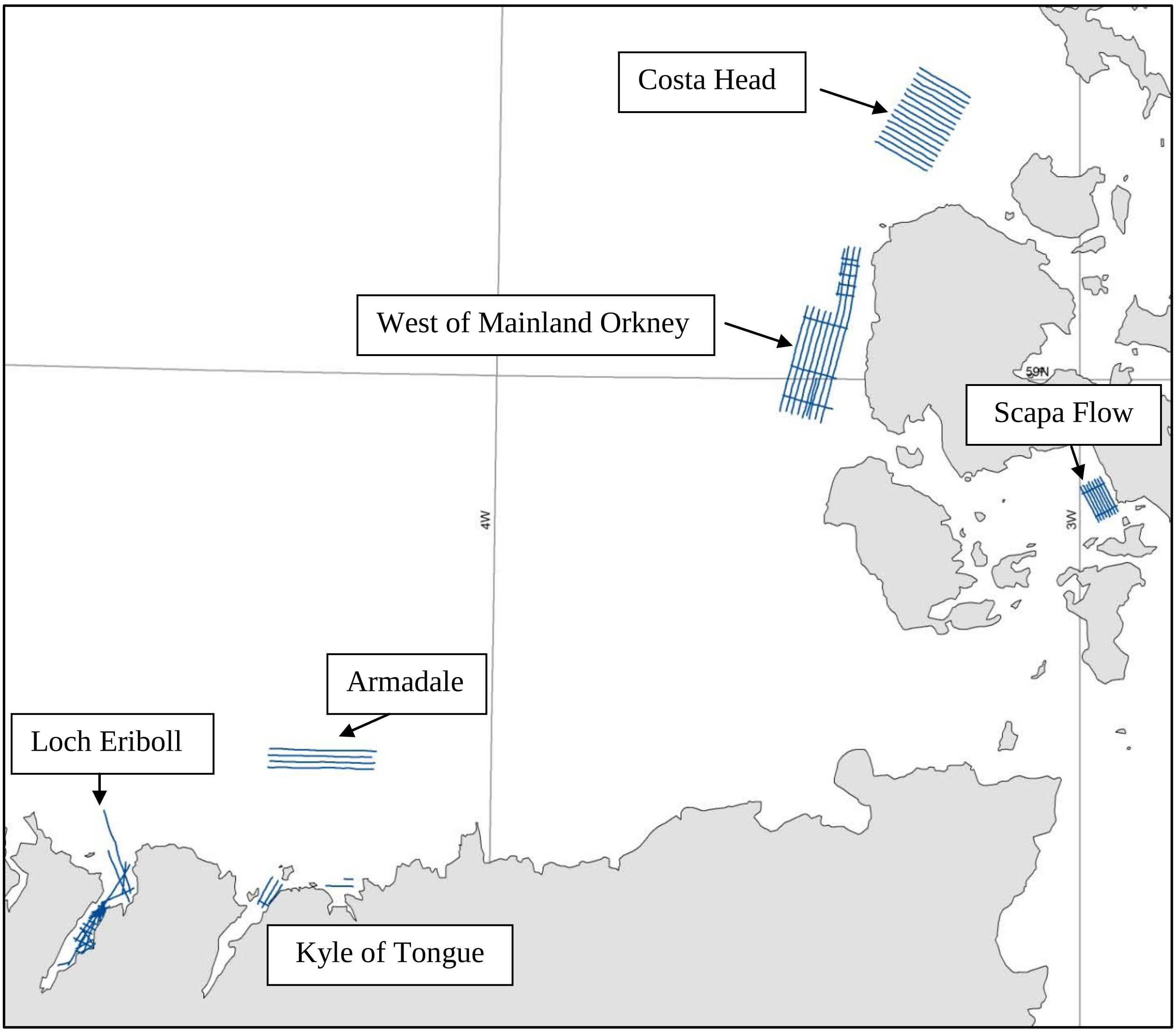

Figure 1. Location map for the six seismic surveys.

Additional secondary sites on the eastern side of Scapa Flow, the Kyle of Tongue and Loch Eriboll (Figure 1) served as backup in case of adverse weather. All three sites were surveyed during the cruise. Camera sledge data were collected in the Costa Head area, and TV sledge data in Loch Eriboll.

2 Seismic interpretation

2.1 INTRODUCTION

In this report an acoustic velocity of 1750 m/s^{-1} (metres per second) is assumed for the sediments overlying bedrock. This gives (for example) a depth of 8.75 metres for each 10 milliseconds in two way travel time (ms TWTT).

In general, the seismic survey data show a reasonably well defined seabed with a series of closely spaced, parallel reflectors to a depth of between 2 and 6 ms TWTT, commonly in the region of 3 ms. This package of reflectors appears to be a constant across all survey areas, and is interpreted to represent the surficial package of modern seabed sediments. Assuming an acoustic velocity of 1750 m/s^{-1}, this translates to a surficial package of sediments up to 5 m thick, but more commonly 2.0 to 2.5 m in thickness. There are potential errors associated with both the assumption of acoustic velocity of the sediment and in interpretation of the reflectors.

The requirement for siting of seabed embedment anchors is typically 6 m of sediment overlying bedrock, which equates to roughly 8 ms TWTT. In the discussion below, depths are given in metres as opposed to milliseconds (time).

BGS was asked to provide depth to rockhead contours at 3, 6 and 9 m below seabed. In the survey areas, these contours have been created where possible to give some indication of the areas within which sufficient sediment overlies bedrock. Given the variability in the thickness of the reflectors related to seabed, there is some uncertainty associated with the location of the 3m (4ms TWTT) contour that in parts of the dataset lies within the package of seabed reflectors. This package probably relates to the layer of active seabed sediments (silt, sand and gravel) that overlies older Quaternary sediment.

On seismic sections, seabed has been picked in red, and the surface interpreted to be top bedrock (rockhead) in yellow. The acoustic package between seabed and rockhead has a homogeneous or transparent character with very little internal structure.

In most survey areas there is an assumption that the generally planar surface with a strong acoustic signature represents bedrock. This is plausible in the Armadale, West of Mainland Orkney and Scapa Flow areas, where parallel, shallow dipping reflectors are observed underlying this surface. In the Costa Head area, such reflectors are relatively uncommon and there is no certainty that the reflector identified is bedrock. It should also be emphasised that there are no borehole data in the survey areas that prove the existence of bedrock at a particular depth.

2.2 ARMADALE

In the Armadale area (Figure 2), four east-west lines were shot with lengths of approximately 10.5 km. Seabed lies at roughly 65 m below OD in the south-eastern part of the study area, falling to 90 m in the north and west. Rockhead also dips towards the north and west, falling from roughly 77 m in the east to 98 m in the west.

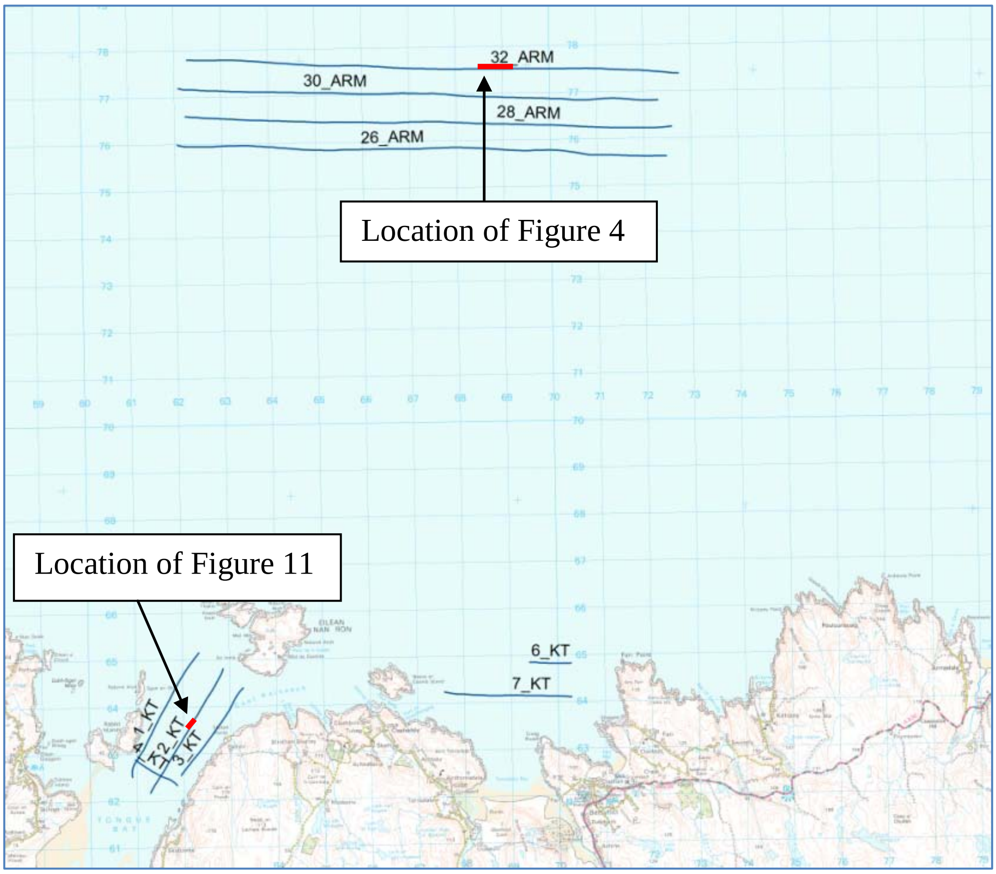

Figure 2. Location of the four lines from the Armadale (ARM) survey in the north and the 6 lines from the Kyle of Tongue (KT) surveys.

Depth to rockhead contours have been picked at depths of 3, 6, 9 and 18 m (effectively 4, 8, 12 and 23 ms TWTT) below seabed (Figure 3). The six metre contour delimits the areas within which there is sufficient superficial material to allow location of seabed embedment anchors.

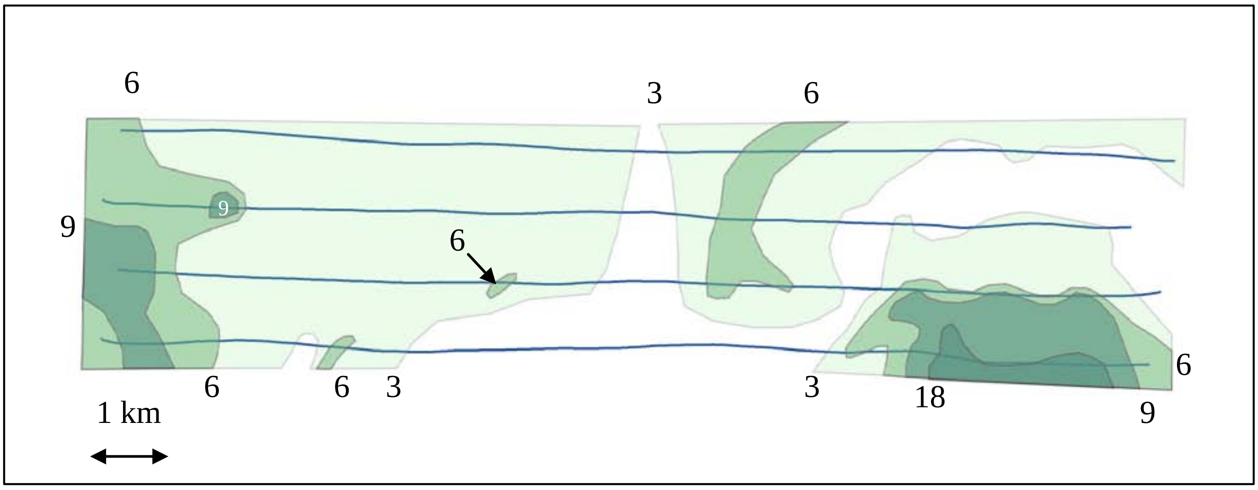

Figure 3. Contours showing depth in metres to rockhead in the Armadale survey area.

Depth to rockhead is in part related to topography at seabed. The rockhead surface is sub horizontal but shows limited topography in the region of 3 to 7 m. The thickness changes of the overlying drift, as shown in Figure 3, generally reflects the pattern of glacial moraines.

The morphology of the moraine ridges is complex (Figure 3) and in the small area a number of ridge axes can be discerned. In the area, several morainic ridges have been mapped by Hubbard et al. (2009) which have common north-east to south-west orientations.

Bedrock reflectors dip commonly to the west, but in north-east of survey an antiform axis is seen trending north-north-west to south-south-east (lines 32, 30 & 28 only). The presence of dipping reflectors throughout the Armadale survey lines suggests that the boundary between Moine and Lewisian rocks in the south and Permo-Triassic rocks to the north lies to the south of the survey area.

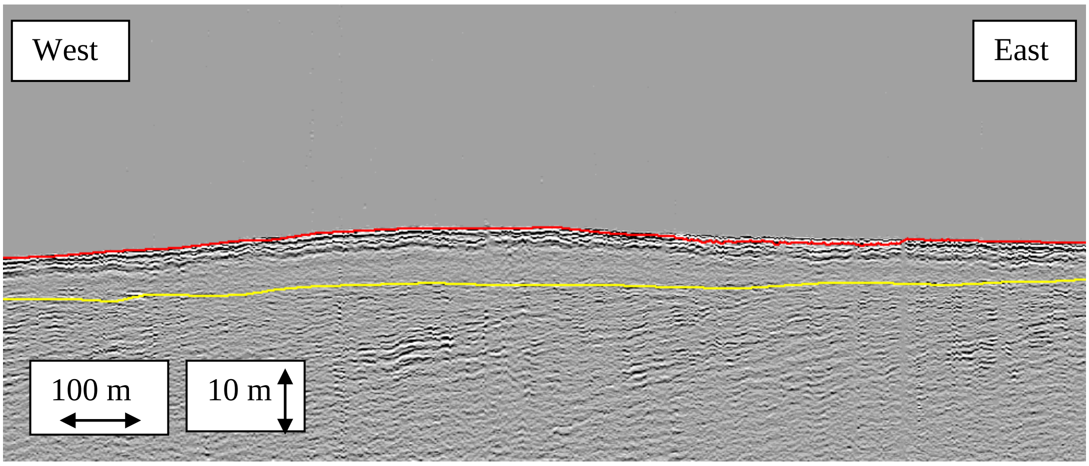

Figure 4. Example of seismic line 32_ARM showing mounded glacial deposits overlying a planar rockhead (yellow) with underlying bedrock reflectors dipping to the west.

2.3 COSTA HEAD

Fifteen lines running roughly north-west to south-east were run in this survey area (Figure 5). In the Costa Head survey area, seabed lies at roughly 75 m below OD, falling to 82 m depth in the far north of the survey area. This data set has little information on sub seabed geology other than local thin lenses picked on single lines, so rockhead has not been contoured but can be assumed to be less than 5 m in thickness throughout the area.

The seabed reflection is clear, with a number of parallel reflectors underlying it in the topmost 4 m of the sediment column. The base of these reflectors can be picked, however it is not certain that this base represents a shallow geological unit of simply the base of seismic ‘ghosting’ associated with the seabed.

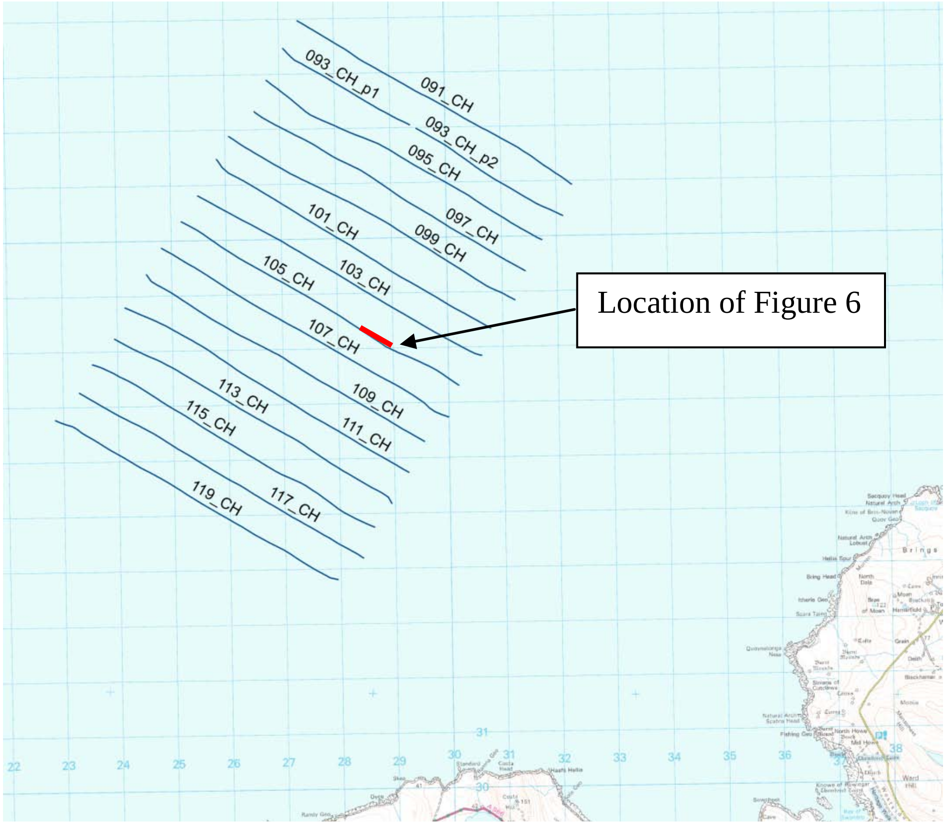

Figure 5. Location of the Costa Head survey lines north-west of mainland Orkney.

Locally, a moderate amplitude reflector can be identified within 4-8 m of the seabed (Figure 6). This is considered to be a geological surface, presumably the base of sediments overlying rockhead. This reflector is not common in the area of study and cannot be traced for more than several hundred metres locally.

Multibeam imagery of the area shows a generally planar seabed. A small number of ridges have been mapped in the area. These parallel ridges are narrow and have an arcuate geometry that is convex to the north-west. It is uncertain whether these arcuate ridges correspond to the low ridges observed in seismic sections (Figure 6).

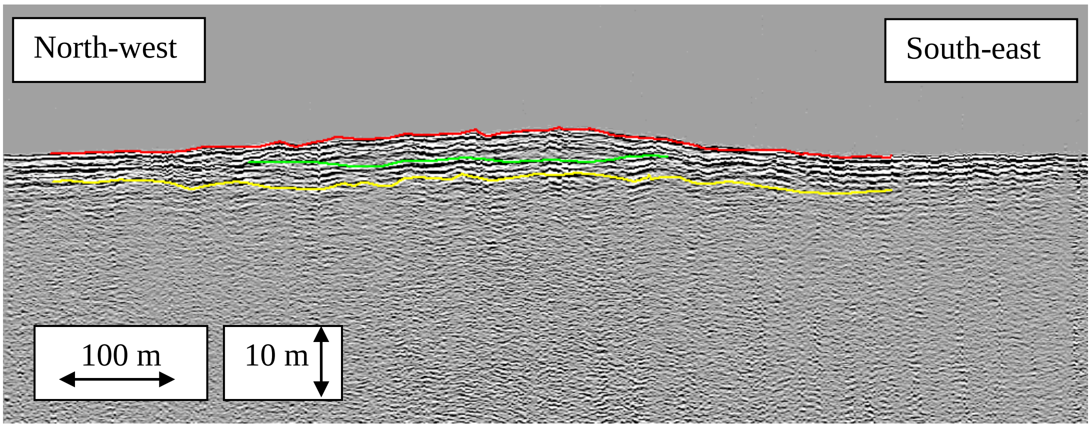

Figure 6. Small section of line 105_CH showing an area in which some sub seabed detail can be discerned. Rockhead (yellow) can only be followed for half a kilometre. Very faint reflectors dipping towards the north-west below the yellow reflector might be bedrock.

The depth to rockhead has not been contoured in this survey area, as definition of the surface is poor throughout the survey. If rockhead is present within the range of the survey data then it is difficult to distinguish from the reflectors associated with seabed.

Bedrock reflectors are faint (Figure 6) and cannot be identified throughout the survey. Where they are seen they dip towards the north-west or are horizontal, except in the east and north of the survey area (line 095) where they appear to dip towards the south-west, forming an antiformal axis running approximately north-south. A synformal axis is shown on the BGS 1:500 000 Orkney Solid Geology map sheet running from north to south just to the east of the survey area, the structure imaged in the survey area might be a subsidiary fold of the main axis.

2.4 WEST OF MAINLAND ORKNEY

To the west of Mainland Orkney seabed lies at 75 m below OD in the south-west of the area, rising to 52 m in the north-east. Rockhead in the area is at approximately 83 m in the south-west, falling to 62 m in the north-east.

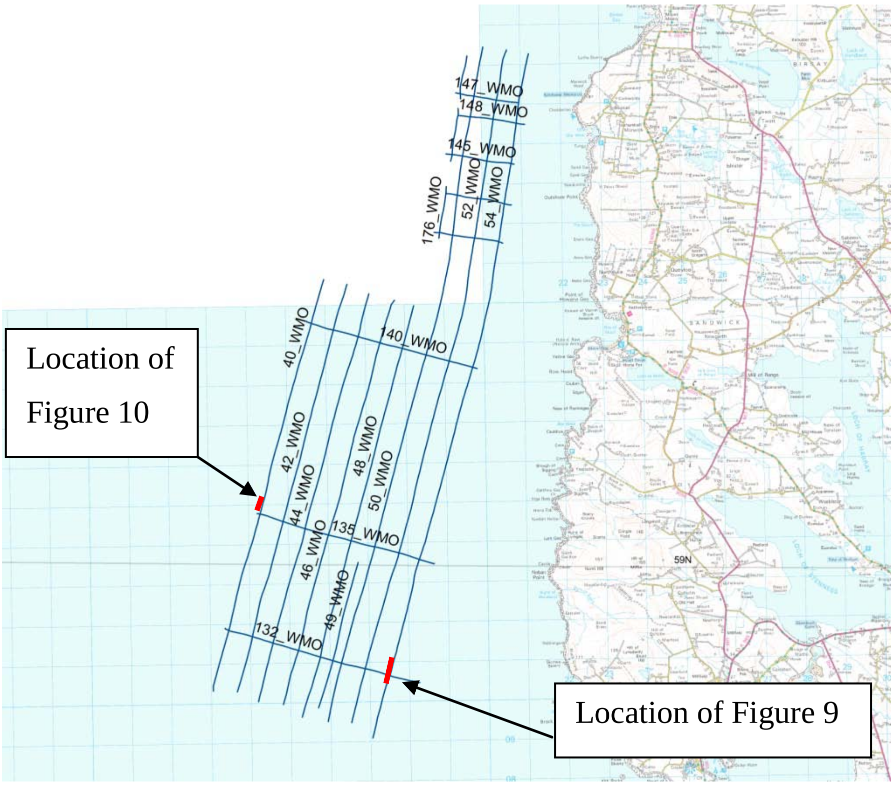

Figure 7. Location of the survey lines west of mainland Orkney.

Contours to rockhead are drawn at 3, 6, 9 and 18 m. The rockhead surface is commonly planar and sub-horizontal, with uncommon local topography. The overlying superficial deposits, therefore, define a mounded topography that suggests a network of glacial moraines. There is no predominant orientation for the features shown in Figure 8, however multibeam data show a number of generally north-south oriented features to the north of this dataset. It is possible that the northernmost feature in the survey area forms part of the network of north-south oriented ridges.

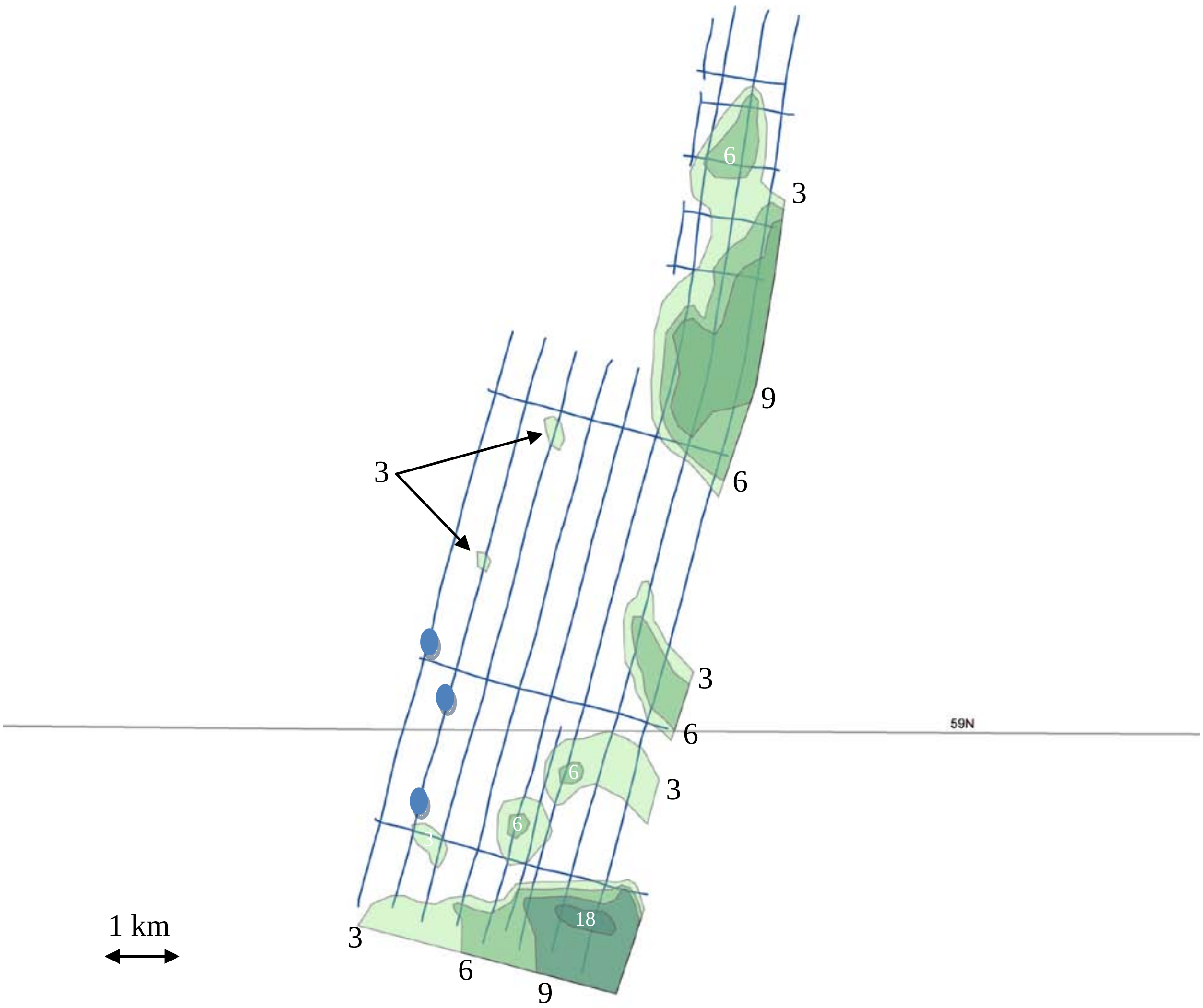

Figure 8. Contours showing depth in metres to rockhead in the West of Mainland Orkney survey area. The blue circles represent the locations of seabed mounds.

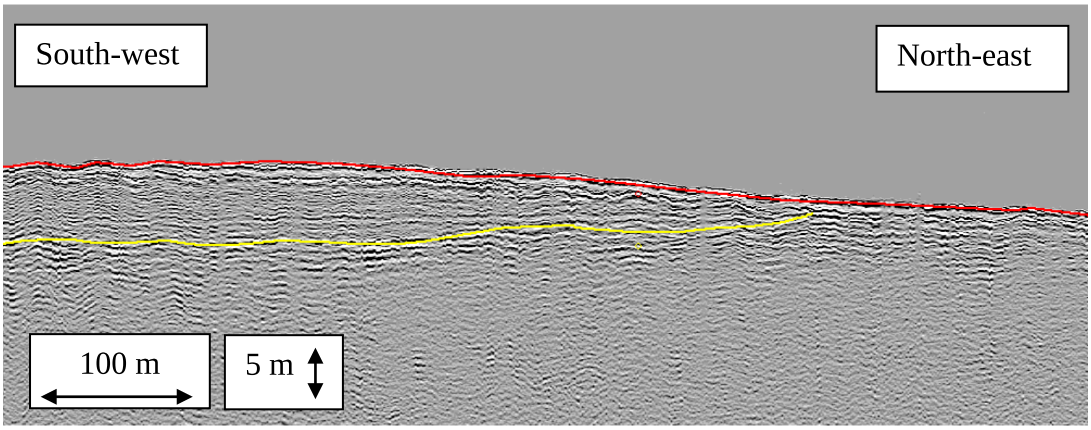

Figure 9. Part of line 54_WMO showing the margin of the southern feature interpreted to be a glacial moraine. Note the uncertainty at the north-eastern edge of the moraine where the rockhead reflector intersects the package of seabed reflectors.

In the west of the survey area several mounds at seabed have been identified (Figure 10). These are 150 to 200 m in diameter and have a height of up to 7 m. There are no internal reflections within these mounds to suggest whether they are bedrock highs or sedimentary bedforms. The absence of any identifiable seismic reflections in the vicinity suggests the former, although this cannot be confirmed with existing data.

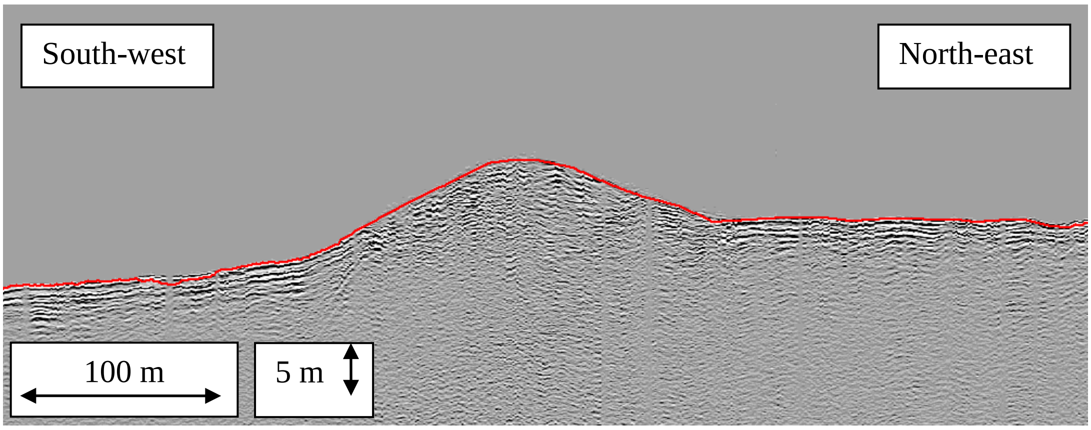

Figure 10. Mound on line 40_WMO, showing poorly defined internal structure.

Bedrock reflectors are difficult to distinguish, but in the north of survey some northerly dipping reflectors can be seen. BGS regional seismic survey data suggest a dip towards the north-west. The contact between older Devonian sedimentary rocks to the east and Permo-Triassic rocks to the west is tentatively interpreted to pass from north to south in the survey area, but there is no evidence from seismic records for the location of this boundary.

2.5 KYLE OF TONGUE

Two east-west trending lines were run in Torrisdale Bay (Figure 2). Both show 2 packages of generally transparent sediment. The upper is between 5 and 8 m in thickness, and thickens from west to east. The base of this package is generally planar. The lower package is between 13 and 26 m in thickness, and generally thickens from east to west. The base of this package might represent rockhead. The reflector marking this surface is indistinct and locally obscured by the multiple, but appears to undulate with a relief of 8.7 and 13 m. In the far west of line 7 there is a lenticular body roughly 200 m across that might represent a channel like feature.

Four lines were shot in the Kyle of Tongue (Figure 2), three running north-east to south-west (parallel to the orientation of the Kyle) and one running north-west to south-east. The seismic stratigraphy is similar to that in Torrisdale Bay, with two packages of sediment overlying an undulating surface that might represent rockhead (Figure 11). The upper package is 10 m in thickness in the south-west farthest inshore, and thins gradually to zero (where it cannot be distinguished from the seabed reflector) to the north and east. In the northern parts of lines 2 and 3 the upper package is not present.

The lower package is commonly in excess of 50 m in the survey area. It contains few reflectors, but can be subdivided in the north of the area where some parallel, sub horizontal surfaces are identified. In the east of the survey, a poorly defined, undulating surface (R) rises to within 26 m of the seabed. This might represent rockhead, but with no other data to confirm this, it is also possible that the surface represents the top of a glacial till. It is probable that depth to bedrock exceeds 6 m throughout the survey area.

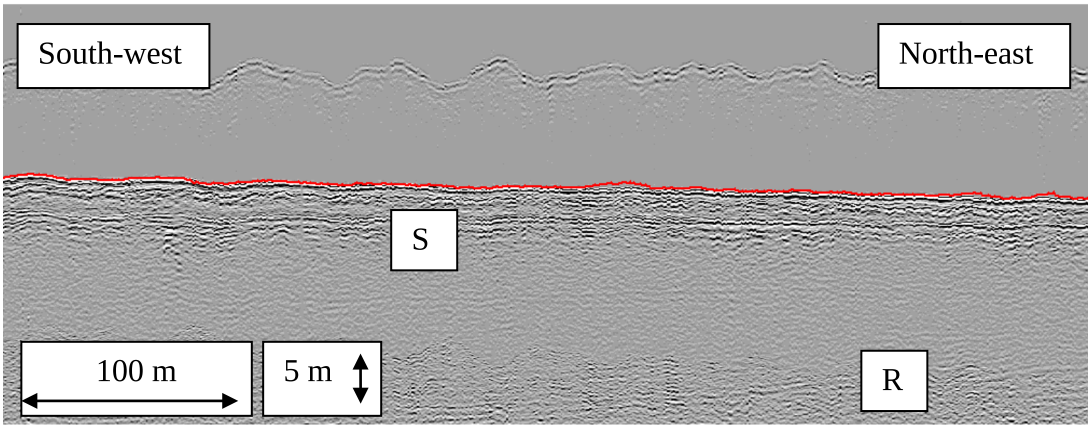

Figure 11. Example seismic section from line 2_KT. The upper package in this line, the base of which is shown on surface S, is only 4 to 5 m in thickness. The poorly defined surface R might represent rockhead.

2.6 LOCH ERIBOLL

Twenty six lines were run in Loch Eriboll (Figure 12). These data show a complex geology, with four or five phases of sedimentation including deposition of mounded deposits that are now buried under later (post glacial?) phases of deposition (Figure 13). The complexity of the geology requires further, detailed study and integration with existing multibeam and offshore datasets which is beyond the remit of this report.

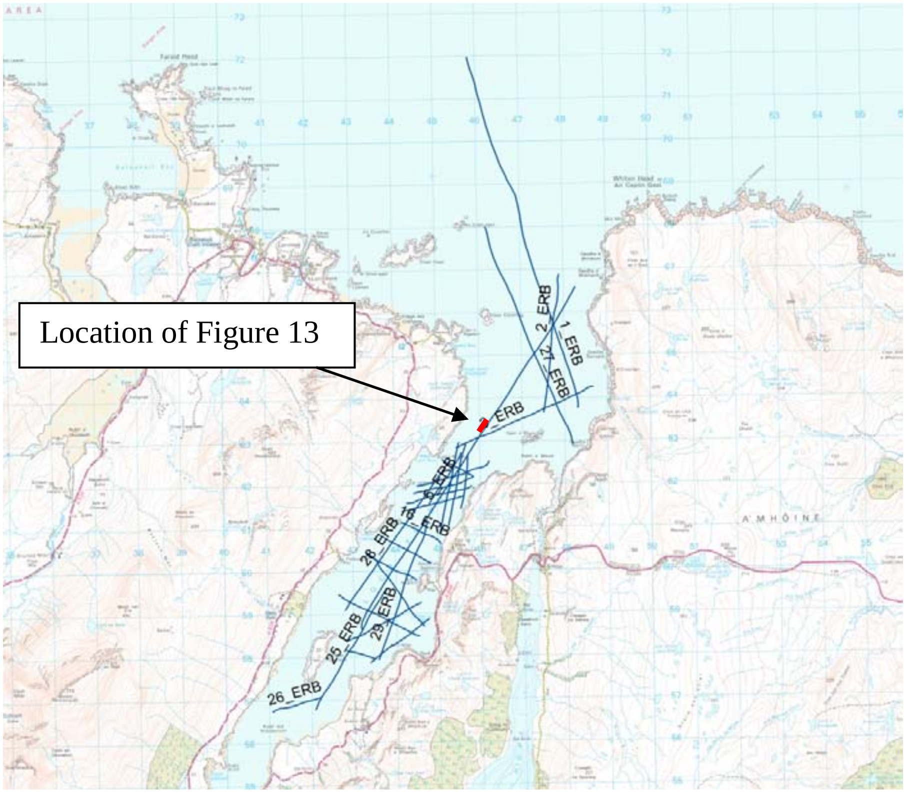

Figure 12. Location of the survey lines in Loch Eriboll.

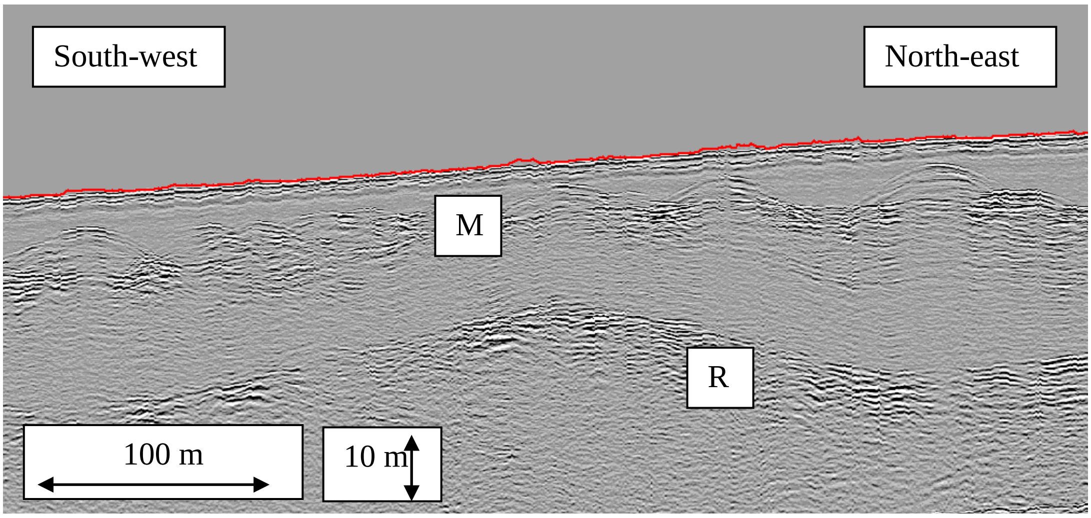

Figure 13. Example of seismic line 25_ERB showing two reflectors. A mounded reflector (M) at 5-10 m below seabed might represent late glacial sand and gravel deposits. The lower undulating surface (R) might represent rockhead, or alternatively show the top of a glacial till.

Depth to bedrock is unknown; however a distinct, irregular but high amplitude surface is present over much of the area. This surface is close to surface in some parts of the area (Figure 13) and below resolution (>70 m) in others, however it is nowhere closer to seabed than 10m. Given the variability in character, it is probable that is represents more than one surface including both rockhead and tillhead. A central part of the inner part of Loch Eriboll, east of Portnancon, has seismic stratigraphy obscured by blanking at a depth of between 2.5 to 4 m. It is probable that, other than in the shallowest margins of the loch, depth to bedrock exceeds 6 m throughout the survey area.

2.7 SCAPA FLOW

Ten lines were run in Scapa Flow (Figure 14). In Scapa Flow the planar surface that defines both seabed and much of rockhead lies at roughly 36m below OD in the east, falling to 40m in the north-western corner of the survey area. The package of reflectors in this study area is commonly greater than 4m in thickness. As a result of this and the nature of the bedrock topography, contours to rockhead are picked at 5 and 10 m.

In contrast to the three primary sites described in sections 2.2 to 2.4, depth to rockhead in the Scapa Flow area is mostly related to topography cut into an originally planar rockhead surface (Figure 15). The geometry of the rockhead relief appears to have a dendritic pattern, with zones of maximum thickness forming narrow channels. It is possible that this relates to a period of erosion of the bedrock, possibly by sub aerial (fluvial) processes during a late glacial lowstand when sea level was below the level of the rock platform in Scapa Flow.

Infill of this topography comprises up to 8.7 m of acoustically featureless sediment, overlain by a thin ~4.3 m cover containing several moderate amplitude, sub horizontal reflectors. This might be late glacial sand and gravel overlain by post-glacial transgressive sand, gravel and silt.

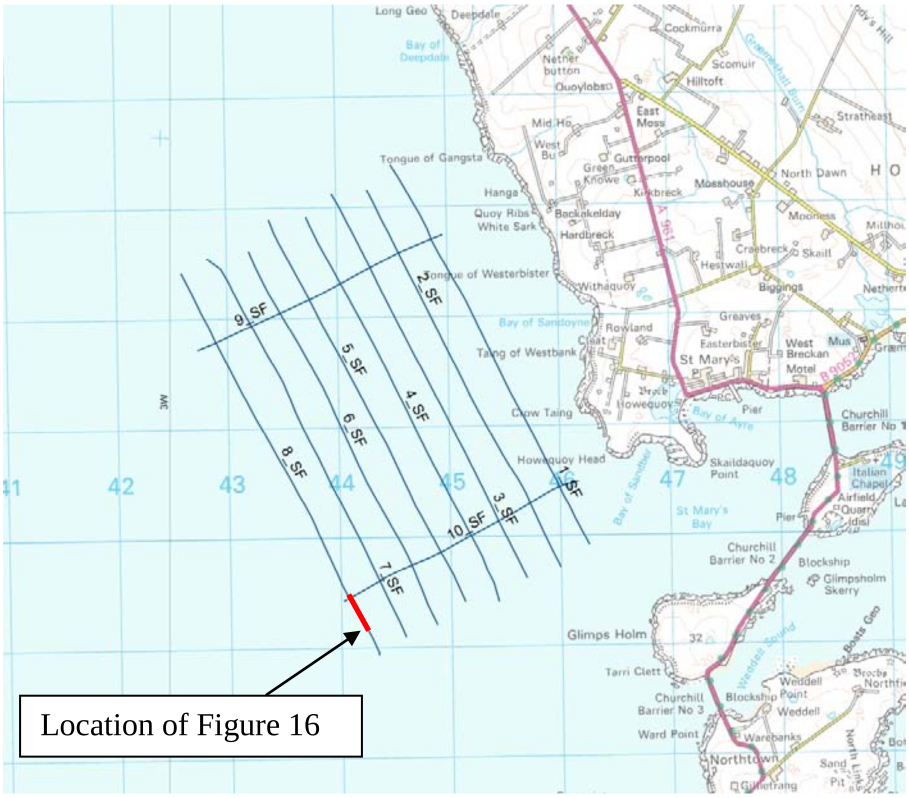

Figure 14. Location of the survey lines in Scapa Flow.

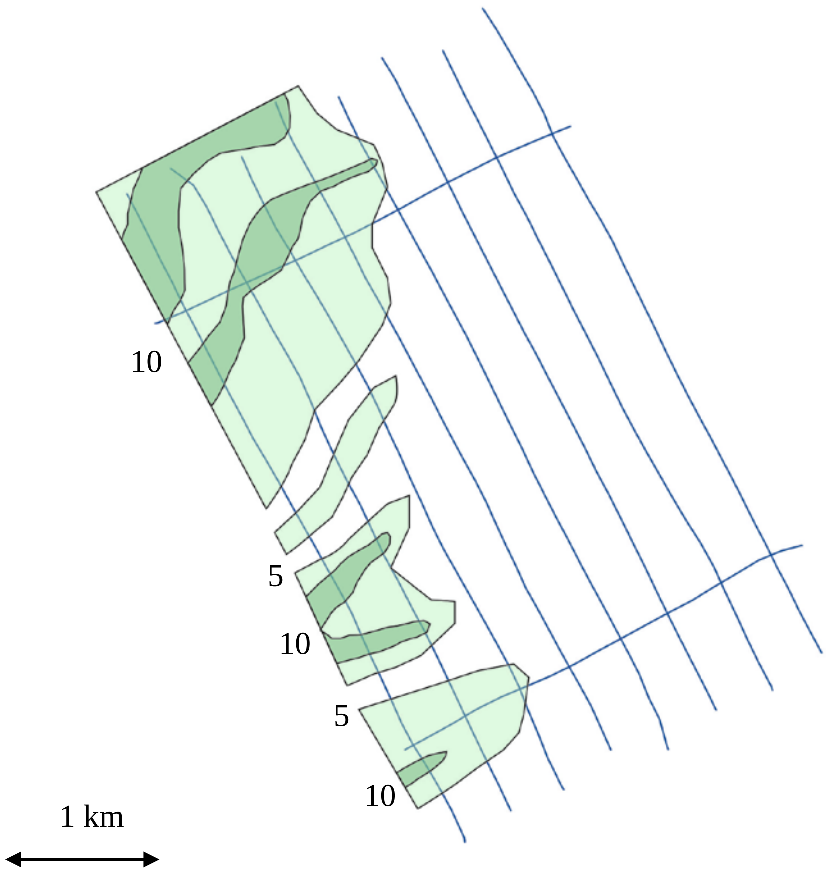

Figure 15. Contours showing depth in metres to rockhead in the Scapa Flow survey area.

One section of elevated topography in the south of the survey has a relief of up to 6 m (Figure 16). It appears to overlie one of the features cut into rockhead which is infilled by sediment containing poorly defined reflectors. The base of this elevated feature is horizontal, i.e. it overlies the incised and infilled rockhead surface, and the boundaries of the feature have a raised profile (Figure 16). It is possible that this feature represents a sediment accumulation created during transgression in the late Pleistocene. Similar features have been recognised in the vicinity of Orkney (Leslie & Stewart, 2004).

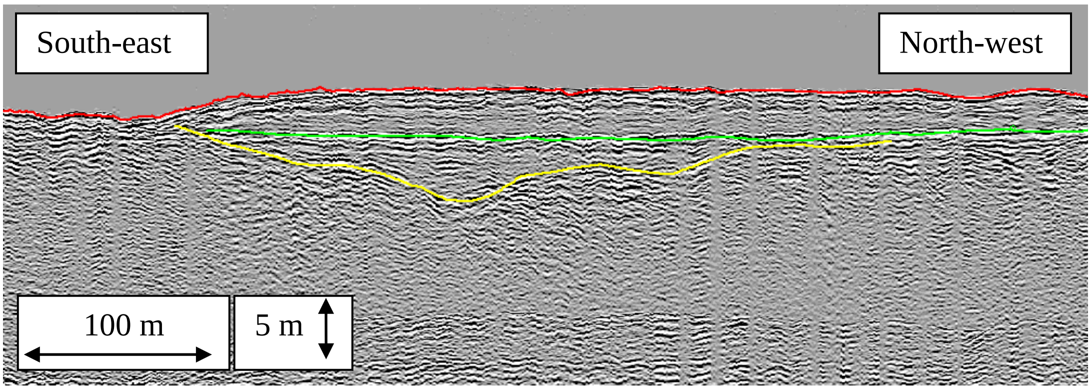

Figure 16. Part of seismic line 8_SF showing the incised rockhead surface (yellow) infilled with sediment (below the green reflector) and overlain by a younger sediment body.

Bedrock reflectors are uncommon but indicate that bedding dips towards the north or is sub-horizontal. Regional seismic lines shot in 1970 also indicate a dip of bedrock towards the north.

3 Conclusions

3.1 PRIMARY AREAS

- In two of the primary areas (Armadale and West of Mainland Orkney) depth to rockhead has been mapped and the areas with sufficient superficial deposits (>6 m) have been identified.

- These areas of thick superficial deposits relate to the location of what are probably glacial moraines.

- Several mounds with topography of up to 6 m have been identified in the West of Mainland Orkney area. The origin of these features is uncertain.

- In the third primary area (Costa Head) there does not appear to be superficial deposits of comparable thickness to the Armadale and remaining West of Mainland Orkney sites; this might however relate to data quality. Thin narrow ridges identified on both seismic and multibeam records appear to be low, narrow features with fewer than 5 m of superficial deposits.

3.2 SECONDARY AREAS

- In the Kyle of Tongue and Loch Eriboll areas, depth to bedrock appears to exceed 6 m throughout the survey areas. Both these areas have complex geology which would benefit from detailed examination combined with multibeam interpretation.

- In the Scapa Flow area depth to bedrock appears to be related mostly to infill of an incised bedrock surface, possibly caused by fluvial processes during a period of lowered sea level.

- The areas of thick superficial deposits in Scapa Flow are relatively narrow, related to the ‘channel’ axes.

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British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: http://geolib.bgs.ac.uk.

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