

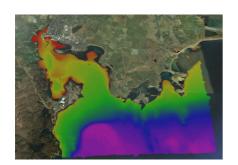
# Aspect Land & Hydrographic Surveys Ltd

Thornhouse Business Centre Ballot Road, Irvine, Ayrshire KA12 0HW Tel: 01294 313 399 Fax: 01294 313 389 E-mail: mail@aspectsurveys.com

Web: www.aspectsurveys.com

# MULTIBEAM AND GEOPHYSICAL SURVEY

# STORNOWAY HARBOUR



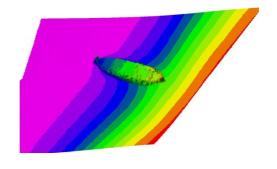
ISLE OF LEWIS

**SCOTLAND** 

**SURVEY REPORT** 

A5006

10 May 2013



COMPILED: E J STACEY

APPROVED: C D THOMSON

#### Client:

Stornoway Port Authority Amity House Esplanade Quay Stornoway Isle of Lewis HS1 2XS



















# Contents

1.	Introduction	4
2.	Description of Site / Geomorphology	5
3.	Scope of Works	5
4.	Geodesy & Datum	6
5.	Bathymetric Survey	6
6.	Sub-Bottom Profiling.	8
7.	Side-Scan Sonar Survey	9
8.	Magnetometer Survey	10
9.	Site Specific Area Descriptions	11
9.1	Inner Harbour Area	11
9.2	Area 1	13
9.2.1	I Area 1 Geophysical Interpretation	15
9.3	Area 2	16
9.3.1	I Area 2 Geophysical Interpretation	17
9.4	Area 3	19
9.4.1	I Area 3 Geophysical Interpretation	21
9.5	Area 4	24
9.5.1	I Area 4 Geophysical Interpretation	25
9.5.2	2 Area 4 Magnetometer	26
9.5.3	3 Area 4 Wrecks	26
9.5.4	4 Area 4 Sidescan Sonar Targets	31
9.6	Area 5 Inner Section	40
9.7	Area 5 Outer Section	52
10.	Survey Vessel	58
11.	Survey Standards	59
12.	Personnel	59
Anne	ех А	60
Anne	ех В	60
Anne	ех С	63
Anne	ex D	65
Anne	ех Е	67
Anne	ex F	68



Figures	
Figure 1 - Overview of the survey area, with sub-areas marked in red	
Figure 2 - Overview of the bathymetry in Stornoway Harbour (depths coloured 0 to 40m, red to magenta)	
Figure 3 - R2Sonic 2022 Multibeam system, as used for the bathymetric survey	
Figure 4 - Applied Acoustics boomer system utilised for the sub-bottom profiler surveys	
Figure 5 - Klein 3000 500kHz side-scan sonar system, used for the side-scan sonar survey in Glumaig Harb Area 4	
Figure 6 - Geometrics G882 Caesium Vapour magnetometer as used for the magnetometer survey	
Figure 7 - Bathymetric map superimposed on the Ordnance Survey 1:25k map with a number of linear featu	
interpreted (black pecked lines) and the axes of the longer magnetic anomalies shown as blue pecked lines.	
Figure 8 - 0.5m gridded soundings showing the extents of Area 1, riverine channels and dredge scouring	
Figure 9 - Backscatter data from the multibeam system for Area 1, showing areas of differing sediment type	
(brighter colour corresponds with higher backscatter)	
Figure 10 - Line 1-0009 crossing a sediment-filled feature	
Figure 11 - TIN image generated from 0.5m gridded soundings showing the extents of Area 2	
Figure 12 - Backscatter data from the multibeam system for Area 2, showing areas of differing sediment type (brighter colour corresponds with higher backscatter)	е
, , ,	
Figure 13 - Two lines showing the different elements of the sub-seabed structure and composition of Area 2	
stratified sediments overlying the rugged rockhead topography and the more enigmatic smoother-topped bo	
that may be till or morainic deposits or gas within the substrate.	
Figure 14 - TIN image generated from 0.5m gridded soundings showing the extents of Area 3, Newton Basin	
Figure 15 - Backscatter data from the multibeam system for Area 3, Newton Basin, showing areas of differing a dispersion of the property of th	•
sediment type (brighter colour corresponds with higher backscatter) and linear object (red line highlighted)	
Figure 16 - An extract of the backscatter data for Area 3 showing two tyres on the seabed, close to the slipw	•
(seen on the bottom left of the image) Figure 17 – Linear object seen in Backscatter and Multibeam data running NNE/SSW	
Figure 18 – Bathymetric data for Area 3 superimposed on the Ordnance Survey 1:25 k scale topographical r	
Figure 19 – Line 3-0008: bedrock crops out at seabed near the eastern (left) end and lies close to seabed near	
the western end of the data but is otherwise buried beneath a cover (up to c. 3 m thick) of seismically layere	
deposits unconformably overlain by a drape of sea bed sediment. A marked thickening of the layered	·u
sedimentary sequence is evident at the west end of the section (Mouth of the bay)	23
Figure 20 - TIN image generated from 0.5m gridded soundings showing the extents of Area 4	
Figure 21 - One of a groups of lines across a relatively deep, asymmetrical, erosional bedrock feature, featu	
filled with glacial deposits, the upper part of the sequence showing large-scale cross-bedding in glaciofluvial	
glaciomarine sediment prograding from the eastglaciomarine sediment prograding in glacionavial	
Figure 22 - Undulating bedrock surface with rounded to flat topped body of till/moraine buried by	20
'dished'? glaciomarine or glaciofluvial sediments, possibly sand and gravel, that show slight pondi	ina
against the steep flanks of the bedrock and till features	-
Figure 23 - TIN image of Area 4 generated from 2m sorted data showing background magnetic field strength	
with anomalies in blue (negative) and red (positive)	
Figure 24 - Mosaicked side-scan sonar data for Area 4, Glumaig Harbour	
	აఠ
Figure 25 - Backscatter data from the multibeam system for Area 4, Glumaig, showing areas of differing	20
sediment type (brighter colour corresponds with higher backscatter)	
Figure 26 - TIN image generated from 1m gridded soundings showing the extents of Area 5 Inner	40
Figure 27 - TIN image generated from 2m sorted data showing background magnetic field strength with anomalies in blue (negative) and red (positive), showing the extents of the magnetometer survey	11
anomalies in viue (neualive) and red (vosilive), showing the extents of the magnetometer survey	4 1



Figure 28 - Backscatter data from the multibeam system for Moi Sandwick, Within Area 5 Inner, snowing areas	01
differing sediment type (brighter colour corresponds with higher backscatter)	.48
Figure 29 - Backscatter data from the multibeam system for 22 <sup>nd</sup> February (western side of harbour from end of	)f
No. 1 Pier in the north to the entrance of Glumaig Harbour in the south) within Area 5 Inside, showing areas of	
differing sediment type (brighter colour corresponds with higher backscatter)	.49
Figure 30 - Backscatter data from the multibeam system for 25th February (centre of the harbour from Goat	
Island in the north down to Glumaig Harbour in the south) within Area 5 Inside, showing areas of differing	
sediment type (brighter colour corresponds with higher backscatter)	.50
Figure 31 - Backscatter data from the multibeam system for $26^{th}$ February (eastern side of the harbour from $G_{c}$	oat
Island in the north to Arnish Point in the south) within Area 5 Inside, showing areas of differing sediment type	
(brighter colour corresponds with higher backscatter)	.51
Figure 32 - TIN image generated from 1m gridded data showing the extents of Area 5 Outer	.52
Figure 33 - Backscatter data from the multibeam system for the north-east part of the outer part of Area 5,	
showing areas of differing sediment type (brighter colour corresponds with higher backscatter)	.56
Figure 34 - Backscatter data from the multibeam system for the southern section of the outer part of Area 5,	
showing areas of differing sediment type (brighter colour corresponds with higher backscatter)	.57
Figure 35 - Survey vessel Remote Sensor with multibeam sonar and towed sensors deployed	.58
Table 1 - Information relating to the wrecks apparent in Area 4, Glumaig Harbour.	.27
Table 2 - Side-scan sonar target information for Area 4, Glumaig Harbour	.31
Table 3 - Images taken from side-scan sonar imagery showing contacts identified in Area 4, Glumaig Harbour	
Error! Bookmark not defin	ed.
Table 4 - Information related to wrecks and seafloor objects apparent in the inner part of Area 5	.42
Table 5 - Information relating to wrecks in the outer part of Area 5	.53
Table 6 - Taken from IHO publication S44, Table 1, showing requirements of a Special Order Survey	.59



#### 1. Introduction

On the instructions of Stornoway Port Authority bathymetric, side-scan sonar, magnetometer and sub-bottom profiling surveys were conducted in Stornoway Harbour on the Isle of Lewis, Scotland.

The programme of events was as follows:

Mobilise 18<sup>th</sup> February 2013

Multibeam Sonar Survey 19th February to 4th March 2013

Side-Scan Sonar Survey 20th February 2013

Sub-Bottom Profiler Survey 21st to 23rd February, 1st March 2013

Magnetometer Survey 20<sup>th</sup> to 28<sup>th</sup> February and 4<sup>th</sup> March 2013

Sunday (Non Work Days) 24th February and 3rd March 2013

De-mobilise 4<sup>th</sup> March 2013

The vessel was transported to Stornoway by road and ferry on 18<sup>th</sup> February 2013, and launched at the slipway in the grounds of Lews Castle. The equipment was mobilised on the 18<sup>th</sup> February 2013, allowing a prompt start of survey operations on 19<sup>th</sup> February 2013. The weather conditions throughout the survey were calm, such that there were no adverse effects of the weather on the data collection quality.

For the purposes of this survey Stornoway Harbour was divided into sub-areas, which are shown in Figure 1. Area 1 comprised the inner harbour, along the length of Cromwell Street Quay and down to North Beach Quay. Area 2 comprised the basin to the west of Esplanade Quay.

Area 3 was Newton Basin.

Area 4 was Glumaig Harbour.

Area 5 was the remainder of Stornoway Harbour limits of responsibility. This was further subdivided by a line running east-west through Arnish Point, giving an inner and outer area.

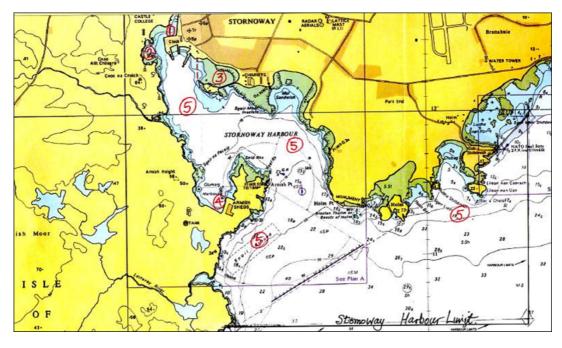


Figure 1 - Overview of the survey area, with sub-areas marked in red



Bathymetric data was collected for the whole harbour, out to the harbour limits illustrated on BA Chart 2529, and extending into as shallow water as was safe and practicable. The magnetometer survey covered the inner part of Area 5, including areas 1 through 4. The sub-bottom profiler survey was undertaken in areas 1 to 4. The side-scan sonar survey took place in area 4 only.

# 2. Description of Site / Geomorphology

The shape of the inlet in which Stornoway Harbour lies is linked closely to the structure of the underlying bedrock. Crushed Lewisian gneiss dominates the harbour geology, which underlies the conglomerate and sandstone characteristic of the Stornoway Beds<sup>1</sup>. The western edge of the harbour lies along the outcrop of a fault juxtaposing the Precambrian Lewisian Complex rocks on the west with the Permian and / or Triassic rocks on the east. The rocks around Stornoway are also cut by north-west trending Tertiary basaltic dykes<sup>2</sup>.

A full background Geological report on Stornoway harbour is available at Annex F.

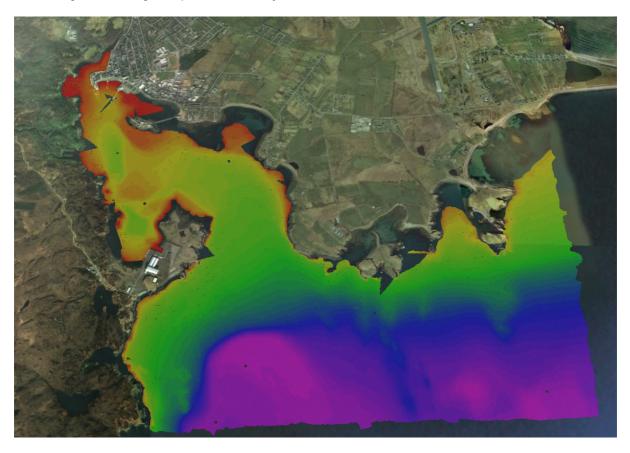


Figure 2 - Overview of the bathymetry in Stornoway Harbour (depths coloured 0 to 40m, red to magenta)

#### 3. Scope of Works

The survey aimed to inform the development of a Port Planning programme as part of a long term strategic plan, and as such comprehensive coverage of the harbour was required.

The multibeam survey was conducted to provide 100% coverage of the seabed in the entire area of interest. The multibeam bathymetry also provided the basis for accurately forming sub-seabed features so that they could be

<sup>&</sup>lt;sup>1</sup> Ramsay, D.L. and Brampton, A.H. 2000. Scottish Natural Heritage RSM No. 150 'Coastal Cells in Scotland: Cells 8 & 9 – The Western Isles'.

<sup>&</sup>lt;sup>2</sup> Barnes, R. 2013. GeoloGIS Report 2013/01 'Geological information for Stornoway Harbour'.



related to Chart Datum. As part of the multibeam survey backscatter data was also collected in order to allow the determination of seafloor sediment types and geomorphology.

The sub-bottom profiling survey aimed to determine the depth to bedrock and identify any significant near-surface geological structures.

The side-scan sonar survey was restriced to Area 4 and aimed to identify significant sonar targets in the area of interest, with a view to identifying any objects of apparent archaeological potential.

The magnetometer survey aimed to highlight the presence of cables, pipelines, wrecks and other metallic objects that may impact on any development.

## 4. Geodesy & Datum

The horizontal datum used throughout the data gathering phase of the survey was OSGB36 (OSTN02™). Data has been rendered in OSGB36 Datum, British National Grid. The vertical datum for all rendered data is Chart Datum, which for Stornoway Harbour lies 2.71m below Ordnance Datum. On all of the drawings provided, depths below Chart Datum are positive and depths above Chart Datum are negative.

OSTN02<sup>TM</sup> defines OSGB36 National Grid in conjunction with the National GPS Network. In this respect OSTN02<sup>TM</sup> can be considered error free (not including any GPS positional errors). The agreement between OSTN02<sup>TM</sup> and the old triangulation network stations (down to  $3^{rd}$  order) is 0.1m rms.

## Bathymetric Survey

The R2Sonic 2022 multibeam sonar system (Figure 3 - R2Sonic 2022 Multibeam system, as used for the bathymetric survey) was controlled using R2Sonic Sonic Control 2000 software during the course of data gathering. Very detailed data with full seafloor coverage could be gathered over the area of the survey as a result of the R2Sonic 2022's narrow beam width (1.0°) and high ping rate, and the selection of 400kHz as an operating frequency. The system was operated at the maximum ping rate achievable throughout the survey, such that the ping rate was controlled by the depth of water.

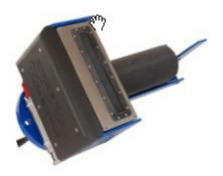


Figure 3 - R2Sonic 2022 Multibeam system, as used for the bathymetric survey

Sound Velocity (SV) dips were carried out prior to commencing survey operations and thereafter whenever the surface sound velocity varied by more than 2ms<sup>-1</sup>. Throughout most of the harbour there was little freshwater input and the waters were well mixed, resulting in little variation over much of the survey area. SV dips were carried out using an AML SVP dipping probe and SeaCast software, and the data incorporated into the Hysweep Survey software for real-time corrections.



Positioning was achieved using a Trimble MS860 RTK GPS system, providing horizontal and vertical positioning as well as precise heading. Full motion compensation for use in the multibeam sonar data gathering system was provided by way of an OxTS Inertial+motion reference unit mounted directly next to the sonar head, providing high quality and frequent motion compensation as required by the multibeam sonar system. The OxTS Inertial+inertial navigation system was used to improve the solution of the GPS receiver. The precision of the RTK system allowed the RTK height to be utilised for tidal reduction throughout the survey.

The sonar and ancillary sensor data was gathered in the Sonar Interface Module (SIM) on the boat, which combined sonar data from the head, GPS (GGA and ZDA), 1PPS, motion (TSS1) and array face SV. This data was transmitted to the survey laptop running Hypack Hysweep over an Ethernet connection.

Data was gathered with a planned insonification of 200% in order to allow online and post-survey quality assurance checks to be carried out reliably.

Calibration values for the system were calculated from a patch test conducted on the 19<sup>th</sup> February 2013 in the survey area, and checked regularly throughout the course of the survey to ensure that there had been no movement in the sonar system or change in the latency of the GPS system. Details are at Annex C. The calibration values were:

Latency	-0.40
Pitch	-1.00
Roll	-0.60
Yaw	5.50

Data gathering was done in Hypack Hysweep Survey. Hypack was then used to post-process in the MBMax software. The stages of Hypack processing are detailed in Annex D. Further processing and quality assurance was done using IVS3D Fledermaus software.

The depths in the survey area ranged between drying heights of around 2m above Chart Datum to depths of 43m below Chart Datum. The survey system used exceeds the requirements of an IHO Special Order survey in all depths experienced during this survey (see Survey Standards section).

Results of the bathymetric survey are shown in the rendered drawings detailed in Annex A.



## 6. Sub-Bottom Profiling.

A lightweight Applied Acoustics boomer system was utilised for the geophysical work.

This system comprises:

High Voltage Power Supply CSP-L 100 Joule

AA201 Boomer Plate (sound source) towed behind the survey vessel

Single element Hydrophone (receiver) towed behind the survey vessel

Chesapeake Analogue to Digital converter

Chesapeake SonarWiz5 on-line data acquisition software



Figure 4 - Applied Acoustics boomer system utilised for the sub-bottom profiler surveys

The sub-bottom profiler survey was conducted between the 21st and the 23rd February 2013 and on the 1st March. The boomer system was chosen as the sensor for this task in order to allow penetration of the sediments and identification of sub-bottom horizons.

The main sub-bottom profiler lines were run at 10m intervals in areas 1 to 4. Cross lines were run at 10m intervals in Area 1, and 100m intervals in the other areas.

The geophysical data was interpreted in Chesapeake SonarWizMap geophysical survey processing software. This allowed full resolution data to be viewed and interpreted with individual horizons digitised as required. Further details of the data processing procedures can be seen in Annex D.

Thicknesses were calculated for all horizons to the seafloor in SonarWiz. These were then landformed (reduced) to the seabed levels obtained from the multibeam survey such that all horizons could be reported as a level to Chart Datum.



# 7. Side-Scan Sonar Survey

A Klein 3000, operating at 500kHz, side-scan sonar was used for the side-scan sonar survey, providing very high quality sonar images of the seabed.

This allowed the morphology of the seabed to be fully understood and small objects to be detected.

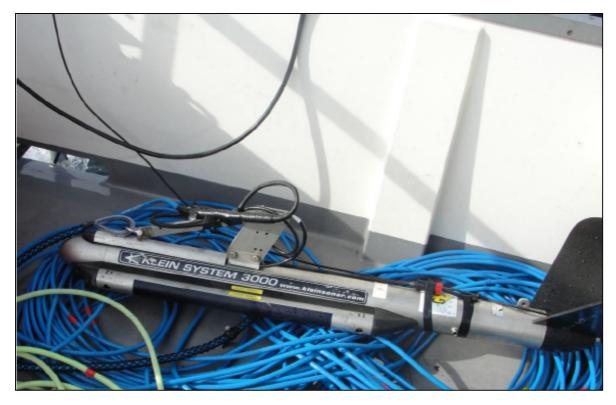


Figure 5 - Klein 3000 500kHz side-scan sonar system, used for the side-scan sonar survey in Glumaig Harbour, Area 4

The side-scan sonar files were processed and mosaicked in Chesapeake SonarWiz software. The generated mosaics were then inserted into an AutoCAD drawing. In order to aid interpretation and provide context, bathymetric contours at 1m intervals have been overlain on the drawings provided. These drawings are listed in Annex A.

The line spacing was 40m, with a range scale of 50m.

Multiple targets were identified in the survey area, which are highlighted in the results for Area 4, Glumaig Harbour.

Details of the side-scan sonar processing procedures are detailed in Annex D.



# 8. Magnetometer Survey

The magnetometer survey was carried out with a Geometrics G882 Caesium Vapour magnetometer which can measure total field strength to a precision of 0.02nT.

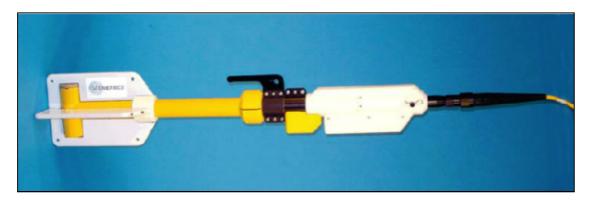


Figure 6 - Geometrics G882 Caesium Vapour magnetometer as used for the magnetometer survey

The magnetometer was towed along multibeam lines. This meant that the line spacing was dictated by the multibeam coverage.

A plot of the background magnetic field strength along with magnetic contacts is rendered as detailed in Annex A.

Details of the data processing procedures used with the magnetometer data are detailed in Annex D.



# 9. Site Specific Area Descriptions

#### 9.1 Inner Harbour Area

The bathymetric data taken in the context of the onshore topography suggests a number of linear features (Figure 7) but no single structure matching the mapped location of the fault between the Lewisian and Permo-Triassic rocks. Instead a broad zone of NW-trending of structures may be present.

An elongate area of deep water south west of Goat Island (Eilean na Gobhail) is bounded to the east by a broad, arcuate ridge joining the island to the Arnish peninsula, this may be in part bedrock but the overall form suggests a glacial moraine, perhaps bifurcating towards the 'mainland' to isolate another area of deeper water within Glumaig Harbour (Area 4). Possibly late-glacial erosional features subsequently cut drainage channels through the ridges.

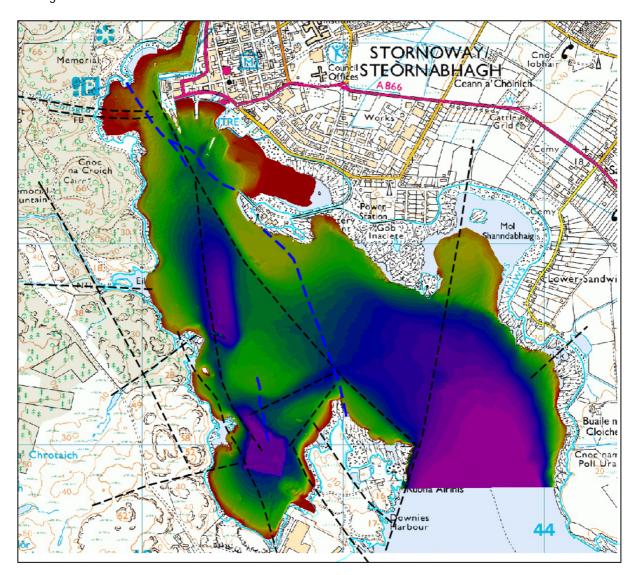


Figure 7 - Bathymetric map superimposed on the Ordnance Survey 1:25k map with a number of linear features interpreted (black pecked lines) and the axes of the longer magnetic anomalies shown as blue pecked lines.

A pronounced, continuous magnetic anomaly passes axially through the harbour: NNW-trending from the north tip of Arnish point towards Goat Island then turning more north-westerly to pass close south west of Goat Island towards the small headland south of Lews Castle. This is likely to be the anomaly shown in Annex F Figure 7, from the regional aeromagnetic data and probably caused by a significant basaltic dyke within the bedrock.



Stevens (1914) describes three dykes at Cuddy Point in the grounds of Lews Castle (Annex F, Fig. 6) and two on the west end of Goat Island; none is known at the tip of Arnish Point, although a dyke is mapped in the isthmus to the west. However, these may be offshoots from the main part of the body lying at some depth concealed witin the Permo-Triassic strata.

Another dyke is suggested by the shorter NNW-trending anomaly in the middle of Glumaig Harbour and may be a continuation of that mapped by Stevens (1914) on the isthmus to Arnish Point.



#### 9.2 Area 1

The bathymetric survey of Area 1 covered a depth range of 2.49m above Chart Datum to 4.33m below Chart Datum. This area contained pontoons and moored vessels, and was limited on the east and south sides by Cromwell Street Quay and North Beach Quay. In the north-east corner seabed channels characteristic of the riverine input can be seen in Figure 8. Evidence of dredging activity can be seen in the deeper areas, with the semi-circular scour patterns indicative of this.

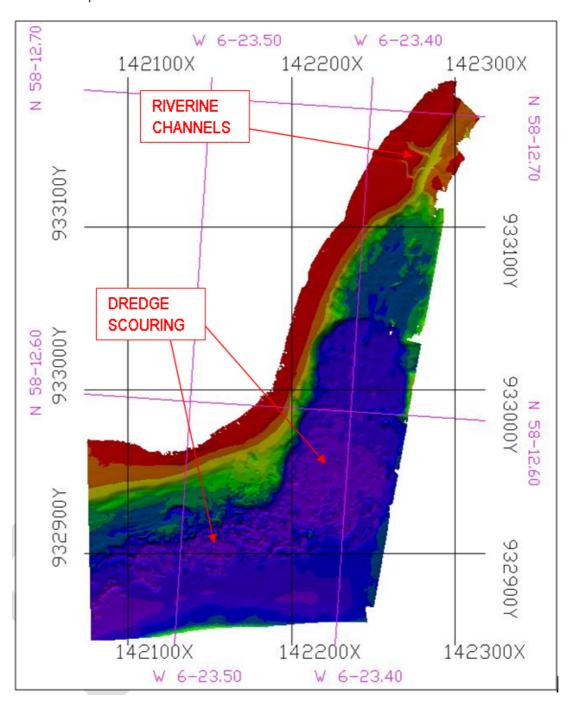


Figure 8 - 0.5m gridded soundings showing the extents of Area 1, riverine channels and dredge scouring

The backscatter data (Figure 9) highlights the scouring patterns seen in the multibeam bathymetry. Areas of low backscatter (dark) can be seen along Cromwell Street Quay in the areas around the pontoons. This suggests that the reduced water movement that may occur in this region as a result of moored boats may have resulted in



the deposition of finer-grained sediments, this is coupled with the difficulties in dredging in these areas resulting in more fine sediment remaining.

The numerous bright, linear features that can be seen along Cromwell Street Quay can be identified as the mooring ropes holding the pontoons in place and not as seabed features. The dredge scours are also shown clearly in the backscatter data.

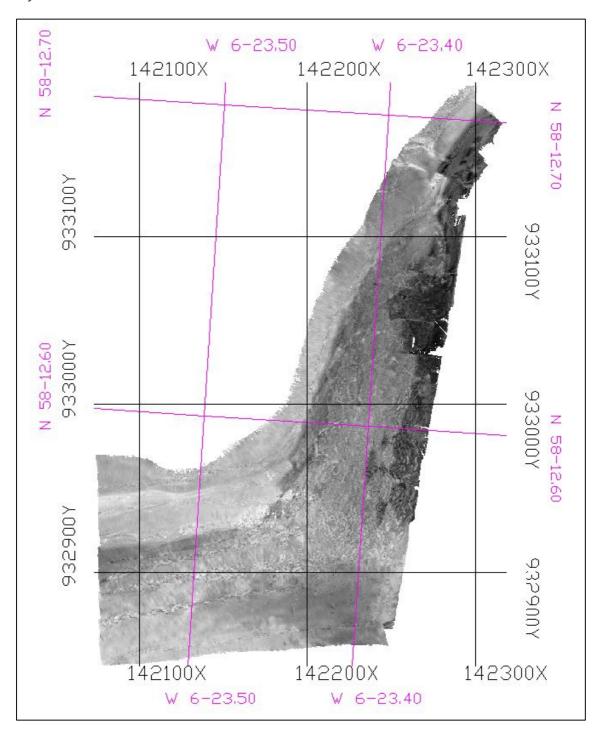


Figure 9 - Backscatter data from the multibeam system for Area 1, showing areas of differing sediment type (brighter colour corresponds with higher backscatter)



# 9.2.1 Area 1 Geophysical Interpretation

The seismic data in this area appear to indicate that the substrate is mainly rock (Permo-Triassic conglomerate) at or near surface, possibly even within the main N-S channel towards the east of the area. The bedrock may have a thin drape of modern marine or intertidal silty mud overlying pockets of sediment with inclined stratification (perhaps glacial sand and gravel) up to 6-8 m thick (e.g. line 1-0009). Thicker sub-seabed sediment sequences with parallel or low angle cross-stratification occur locally, for example filling an elongate hollow (traversed by 1-0009, Fig. A2) to the west of a south-trending bedrock promontory.

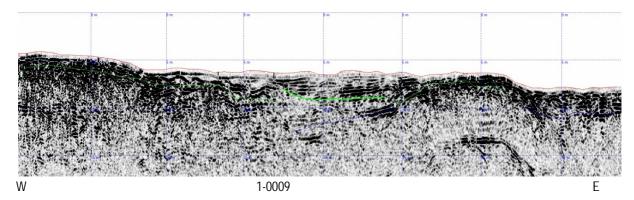


Figure 10 - Line 1-0009 crossing a sediment-filled feature.

A more continuous N-trending sediment-filled feature is seen in the western part of the E-W lines, possibly due to erosion along a strand of the fault zone bounding the Lewisian gneiss (although 150-200 m east of the mapped trace of the fault).

A generally smoother seabed in the southern part of the area marks a more continuous cover of sub-seabed sediments but still of no great thickness.



#### 9.3 Area 2

Area 2, a basin to the west of Esplanade Quay, contained a large concentration of moorings, which can be seen as shallow, round depressions in Figure 11, a rendered image of the bathymetric data. The depth range of this area was from 2.46m above Chart Datum to 6.28m below it. Bounded on the west side by a rocky shore and the east by the Esplanade quay wall, there are also two prominent areas of rock outcropping in the south-west quadrant of Area 2.

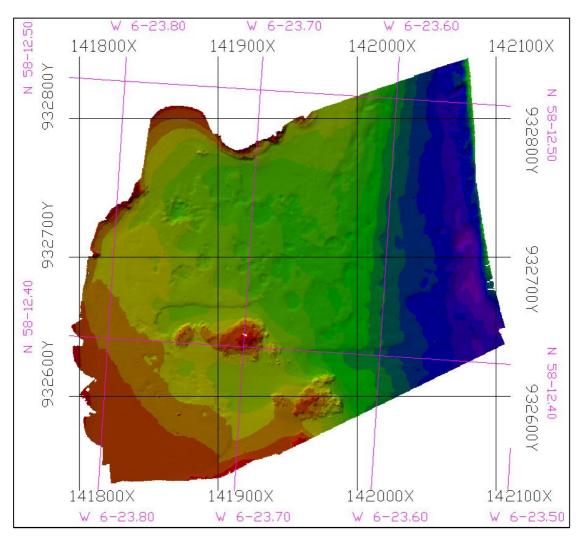


Figure 11 - TIN image generated from 0.5m gridded soundings showing the extents of Area 2

The backscatter data for Area 2 highlights areas of differing sediment types, Figure 12. Darker areas in the mosaic represent areas of lower backscatter, suggesting finer sediment than the surrounding areas.

The rugged areas of rocky outcrops in the bathymetric data appear brighter in the backscatter mosaic as they would be harder and therefore give a higher backscatter return. The backscatter data suggests that a coarser sediment lies along Esplanade Quay than in the basin itself.



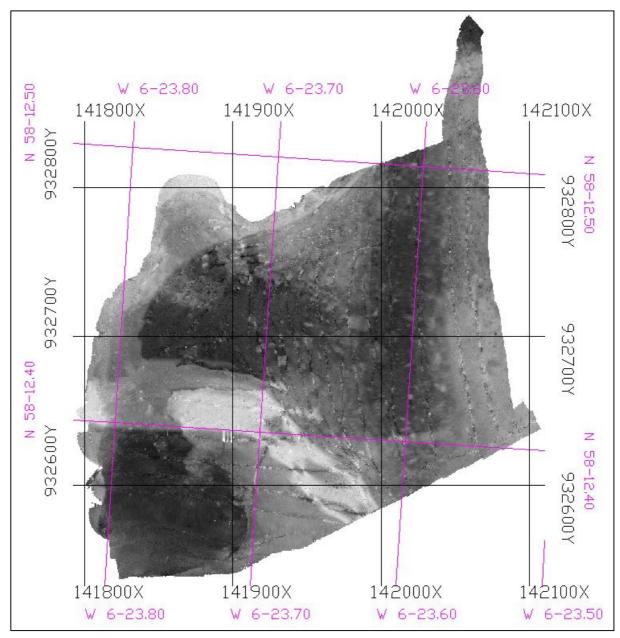


Figure 12 - Backscatter data from the multibeam system for Area 2, showing areas of differing sediment type (brighter colour corresponds with higher backscatter)

## 9.3.1 Area 2 Geophysical Interpretation

The bathymetric data show a very gently east-shelving seafloor 'platform' broken by bedrock outcrops in the southern part, passing over a steeper slope into the deeper channel to the east of the area. In the vicinity of the outcrops, the surface is offset by E-trending features that appear to be a continuation of features evident on land to the west.

From the boomer data, the bedrock outcrops are the tips of a rugged 10-15 m topography underlying the entire platform area of the bay. Sharp knolls are evident separating often narrow, wedge-shaped hollows, including one feature continuous across several lines close to the NNE-trending shoreline in the north of the bay. However, broader ridges or mounds of seismically opaque material (possibly consisting of marainic or gas filled deposits) have a relatively flat or gently undulating top surface (e.g. lines 2-0024 & 2-0022 (Horizon 1 - yellow line in images below and depicted in red in the rendered drawings); Fig. 12); this material seems to consistently underlie the outer edge of the 'platform' area.



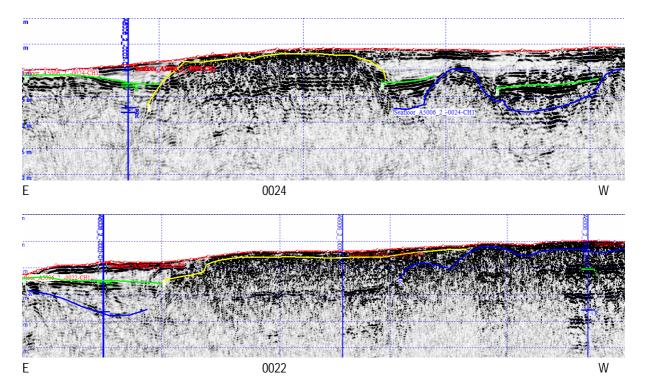


Figure 13 - Two lines showing the different elements of the sub-seabed structure and composition of Area 2 with stratified sediments overlying the rugged rockhead topography and the more enigmatic smoother-topped bodies that may be till or morainic deposits or gas within the substrate.

This mostly sub-seabed topography is buried by a succession of seismically layered and more transparent sediments in which the stratification is commonly gently inclined, locally with wedge-shaped thickness variations. Similar deposits, with more pronounced west-thickening in the seismically transparent material, is present more continuously along the eastern edge of the data underlying part of the slope and the deeper channel.

A thin parallel layered drape seems to blanket much of the sea bed.

The rugged topography underlying parts of the platform and locally protruding at the sea bed is likely to be rock (Lewisian gneiss); the layered sediments that mostly bury this topography possibly glaciofluvial or glaciomarine deposits (if so ranging from sand to gravel); all draped with a blanket of post-glacial sediment possibly analogous to the Annie sequence offshore.

The smoother topped ridges / mounds of Horizon 1 are enigmatic: it is possible that they are bodies of gas, trapped by the overlying mud, that blank the internal structure within the sand/gravel deposits. However, the apparent detail of the dip and thickening of the layered sediments against these bodies in places is suggestive of something more substantial that was present during deposition.

It is difficult to rule out bedrock but the smoother form lead to an alternative explanation as relict bodies of glacial till or moraine deposits sculpted by meltwater prior to inundation and burial by the sand and gravel. If not bedrock, the acoustic energy generally fails to penetrate sufficiently to give a clear response from the underlying bedrock.



#### 9.4 Area 3

Area 3, Newtown Basin, had a depth range of 2.26m above Chart Datum to 7.39m below it. Similarly to Area 2, there were multiple moorings observed, which can be seen as shallow, round depressions in the multibeam bathymetric data Figure 14. Many of these moorings are connected to the shore with fixed mooring lines preventing a complete survey of the area in particular with the boomer system. The slipway structure of the boat yard located on the south side of this area can clearly be seen in the bathymetric data, and the armour stone around the piers can be seen in the north-west section.

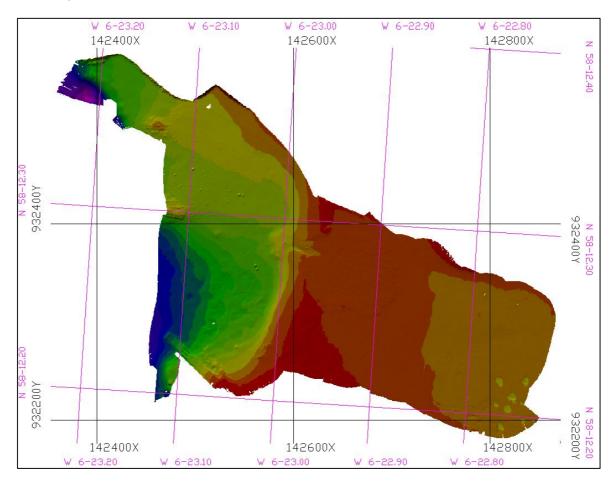


Figure 14 - TIN image generated from 0.5m gridded soundings showing the extents of Area 3, Newton Basin

The backscatter data for Newton Basin shows several areas of different sediment types, and highlights features of the basin such as the pier structure and multiple small objects Figure 15. Around the northern edges, high backscatter interspersed with shadows highlight the armour stone lying around the bottom of No. 3 Pier. The east of the area has much lower backscatter suggesting finer sediment.

The backscatter data for the deeper portion of the basin shows numerous small objects, likely to be boulders, located on the seabed. Figure 16 shows two tyres, located at 142509 932276 and 142508 932283 (58 12 15.06N 006 20 0.55W and 58 12 15.31N 006 23 0.65W). Throughout the areas, many tyres can be seen.

A linear feature can be seen in the north east corner of the area, extending NNE/SSW from the edge of the survey at 142863 932316 (58 12 17.12N 006 22 39.05W) 28m to 142857 932289 (58 12 16.26N 006 22 39.31W). This feature corresponds to the outfall in the image at Figure 17 and is also visible in the multibeam data.



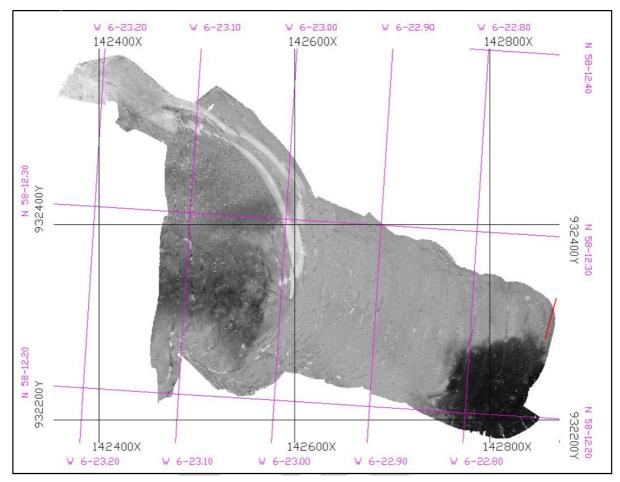


Figure 15 - Backscatter data from the multibeam system for Area 3, Newton Basin, showing areas of differing sediment type (brighter colour corresponds with higher backscatter) and linear object (red line highlighted)

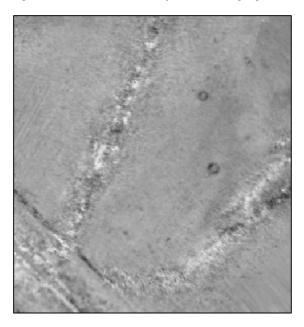


Figure 16 - An extract of the backscatter data for Area 3 showing two tyres on the seabed, close to the slipway (seen on the bottom left of the image)





Figure 17 - Linear object seen in Backscatter and Multibeam data running NNE/SSW

## 9.4.1 Area 3 Geophysical Interpretation

A sheltered bay formed by Battery Point and Goat Island is partly man made as the island was formerly separate from the mainland. An extensive intertidal wave cut rock platform in the back of the bay Figure 18 is composed of Permo-Triassic rocks (conglomerate) dipping c. 20° W; similar rocks are likely to form Goat Island though including basaltic dykes. The NW tip of the island, with a NW-trending jetty extending across the rock outcrop, is linked to the 'mainland' by an intertidal 'beach' ridge, isolating a pool within the bay at low tide. An isolated rock is mapped in the inner part of the bay.



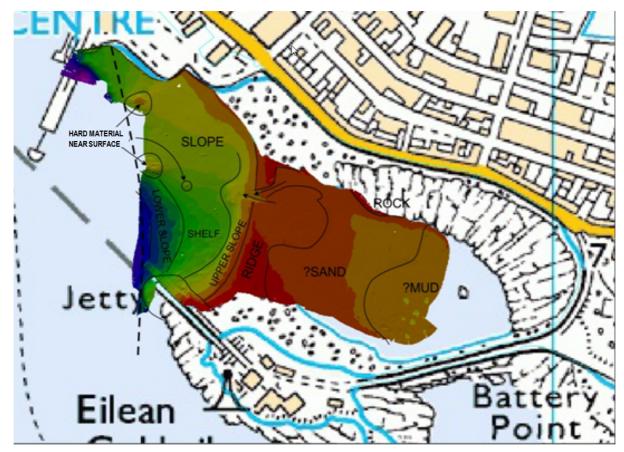


Figure 18 - Bathymetric data for Area 3 superimposed on the Ordnance Survey 1:25 k scale topographical map

The data within the bay end short of the wave cut rock platform but just pick up its edge in the north-eastern part of the data. In the inner part of the bay an area of low backscatter and smooth surface with 'circular' hollows is likely to have a cover of mud. Seaward of this the seabed appears to be characterised by low amplitude sand waves.

The low 'beach' ridge is seen as an irregular area of slightly uneven surface texture. It has a relatively steep seaward-facing slope (upper slope on Figure 18). The last stages of tidal drainage from the bay appears to escape via a shallow channel curving around the north side of the bay and passing through a nick in the ridge, outside of which a small alluvial fan is evident.

West of the ridge the northern part of the seabed in the 'outer' bay is relatively gently sloping southwards with two or three upstanding areas of uneven topography possibly rock outcrops or dumped armour stone. Just outside the main area of interest in Area 3 during the sub bottom profiling survey the nature of these features has not been ascertained.

The southern part has a scalloped shape and stepped profile, with a relatively steep upper slope, a more gently sloping 'shelf' then a steeper lower slope. The shelf has a number of circular or semi-circular features, 10-30 m in diameter with radial texture commensurate with the plentiful boat moorings in the bay.

Rock is again evident at the sea bed on the northern tip of Goat Island in close proximity to a former jetty immediately adjacent to the existing structure.

Seismic lines 3-0008 & 3-0010 just clip the edge of the rock platform in the north of the inner bay, the bedrock appearing structureless on the seismic data, Figure 19. Other areas of rock close to surface may also be evident



within the inner bay (e.g. line 3-0010), possibly coring the northern part of the 'beach' ridge (line 3-0008) and underlying much of the gently sloping area of the northern outer bay (lines 3-0011 to 3-0019).

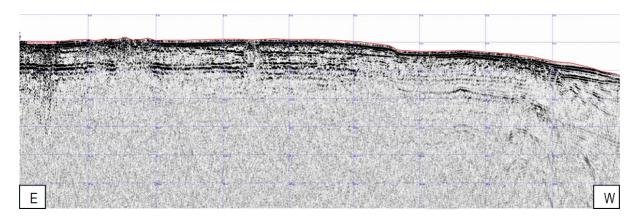


Figure 19 – Line 3-0008: bedrock crops out at seabed near the eastern (left) end and lies close to seabed near the western end of the data but is otherwise buried beneath a cover (up to c. 3 m thick) of seismically layered deposits unconformably overlain by a drape of sea bed sediment. A marked thickening of the layered sedimentary sequence is evident at the west end of the section (Mouth of the bay)

Otherwise, the data show the seabed is mainly composed of a thin drape of seismically laminated marine deposits, possibly equivalent to the Annie sequence of post-glacial mud described offshore (Barnes 2013).

The base of this deposit is an unconformity on the depositional or peneplained surface of deposits within which subhorizontal to very gently inclined layering is often evident suggesting westerly prograding clastic deposits, possibly glaciofluvial or glaciomarine sand and gravel.

The base of these deposits is not imaged. If resting on bedrock this is possibly because (as found in boreholes at Gob Shildinis, Barnes 2013, p 11) the upper part of the underlying conglomerate may be very weathered to decomposed, itself little more than sandy gravel.

At the seaward end of the data a rapidly seaward-thickening wedge of sediment onlaps onto the western rockhead slope, Figure 19. Steeply dipping features evident at depth at the seaward end of the E-W boomer lines correlate with the west edge of the outcrops that form Goat Island and the bedrock knolls to the north; together with the rapid drop in the level of the rockhead surface seawards west of this line, these may suggest a significant feature within the bedrock.



#### 9.5 Area 4

Area 4, Glumaig Harbour, had depths ranging from 2.27m above Chart Datum to 14.55m below Chart Datum. Long, linear markings can be seen on the seabed, which are likely to be anchor scour marks. One well defined wreck and 2 largely covered and dispersed wrecks can be seen in the north of the area, Figure 20 and detailed as Sonar Contacts. On the east side of Glumaig Harbour, in the vicinity of 142750 930750, an area of higher seabed can be seen protruding from the side. This is likely to be dredging spoils which have spread out over time, as the pattern shown is characteristic of this. Areas of rock outcropping can be seen around the edges of the area.

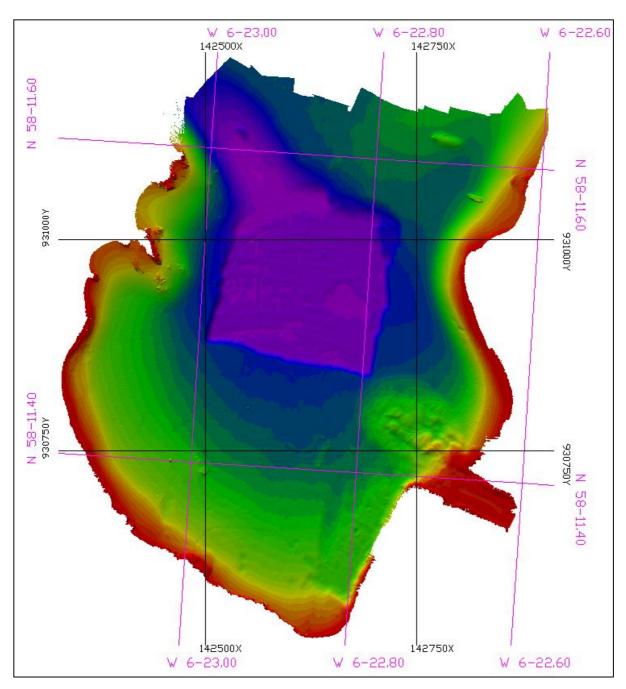


Figure 20 - TIN image generated from 0.5m gridded soundings showing the extents of Area 4



# 9.5.1 Area 4 Geophysical Interpretation

The subsurface data from Area 4 suggest a very similar scenario to that in Area 2. A very irregular rockhead topography on Lewisian gneiss, locally exposed at the sea bed, is largely buried by seismically laminated, moreor less-transparent sediments up to 15 m thick with subhorizontal to gently inclined layering and internal thickness variations 21, suggesting prograding glaciofluvial or glaciomarine clastic (sand and gravel) deposits.

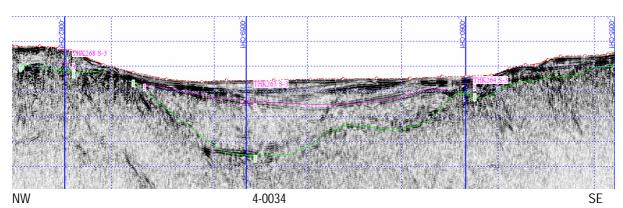


Figure 21 - One of a groups of lines across a relatively deep, asymmetrical, erosional bedrock feature, feature filled with glacial deposits, the upper part of the sequence showing large-scale cross-bedding in glaciofluvial or glaciomarine sediment prograding from the east

Also as in Area 2, rounded or flat topped bodies of seismically opaque material Figure 22 (Horizon 2 yellow digitised line below and blue on the rendered drawing) occur within the layered sedimentary succession; these may be bedrock but are more likely to consist of till / moraine or gas as discussed previously.

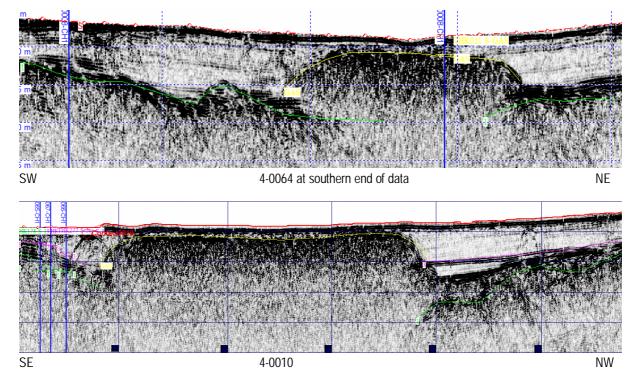


Figure 22 - Undulating bedrock surface with rounded to flat topped body of till/moraine buried by 'dished'? glaciomarine or glaciofluvial sediments, possibly sand and gravel, that show slight ponding against the steep flanks of the bedrock and till features



# 9.5.2 Area 4 Magnetometer

The magnetometer data for Area 4 shows several anomalies. The large anomaly in the south-east corner of the survey Figure 23 is likely to be as a result of the proximity of the pier and dock wall. Other small anomalies may be attributed to wrecks and other debris related to Glumaig Harbour's proximity to a fabrication yard.

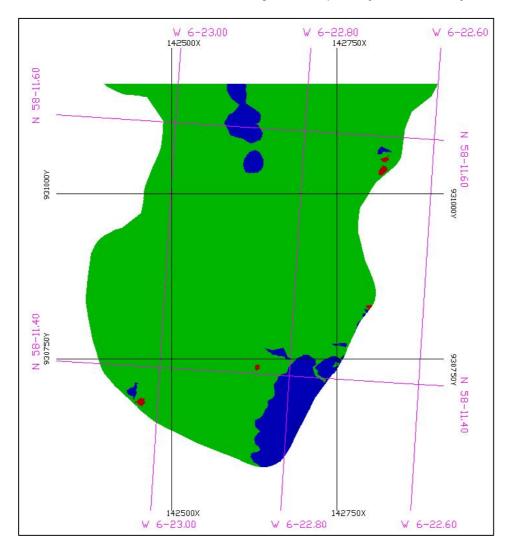


Figure 23 - TIN image of Area 4 generated from 2m sorted data showing background magnetic field strength, with anomalies in blue (negative) and red (positive)

#### 9.5.3 Area 4 Wrecks

Several possible wreck sites were apparent in Glumaig Harbour, detailed below. The wreck at 142544 931127 (58 11 38.10N 006 22 53.83W) may be the Marjory, a wooden motor fishing vessel cited to have been lost in 1948<sup>3</sup>. There is no discernable magnetic signature over this contact. It is possible that the wreck at 142785 931116 (58 11 38.26N 006 22 39.10W) is the Andalina<sup>4</sup>. Again there is no discernable magnetic signature of the wreck.

Although the information relating to the identity of the wrecks is old, and there is a suggestion that wreck removal has taken place since the records were updated the position of these 2 wrecks compared to their listed position lends confidence.

<sup>&</sup>lt;sup>3</sup> http://canmore.rcahms.gov.uk/en/site/102846/details/marjory+arnish+point+stornoway+lewis+north+minch/

<sup>4</sup> http://canmore.rcahms.gov.uk/en/site/102826/details/andalina+seid+rocks+cala+ghlumaig+lewis+north+minch/

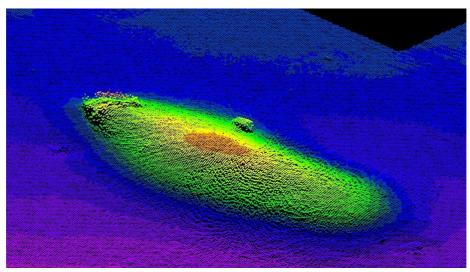


Table 1 - Information relating to the wrecks and significant sonar contacts in Area 4, Glumaig Harbour.

A5006_SSS_13	3				
Position (E/N)	Position (WGS84)	Dimensions (Length x Breadth x Height above seabed)	Surrounding Depth (Chart Datum)	Least Depth (Chart Datum)	Remarks
above seabed)  142818 931048  58 11 36.14N 006 22 36.81W  19.9 x 5.6 x 1.7m			5-8m	2.98m	Largely intact wreck in shallow water. Significant Magnetic Signature. Frames visible on Sidescan



A5006_SSS_11							
A5006_SSS_11 Position (E/N) 142785 931116	Position (WGS84) 58 11 38.26N 006 22 39.10 W	Dimensions (Length x Breadth x Height above seabed) 35.5 x 10.7 x 1.6m	Surrounding Depth (Chart Datum) 8-9m	Least Depth (Chart Datum) 5.49m	Suspected remains of the known wreck Andalina. Last divers report detailed a boiler as the		
					last remains. This may be		
					the visible object in the		
					images below.		







A5006_SSS		1			1
Position (E/N)	Position (WGS84)	Dimensions (Length x Breadth x Height above seabed)	Surrounding Depth (Chart Datum)	Least Depth (Chart Datum)	Remarks
142544 931127	58 11 38.10N 006 22 53.83W	18.1 x 6.3 x 1.2m	13-14m	11.53m	Suspected remains of the known wreck Marjory. A wooden fishing vessel. Last divers report detailed the wreck as very broken up at the stern with rudder still standing. This may be the visible to the bottom right of the image below with some further raised debrist to the north west.



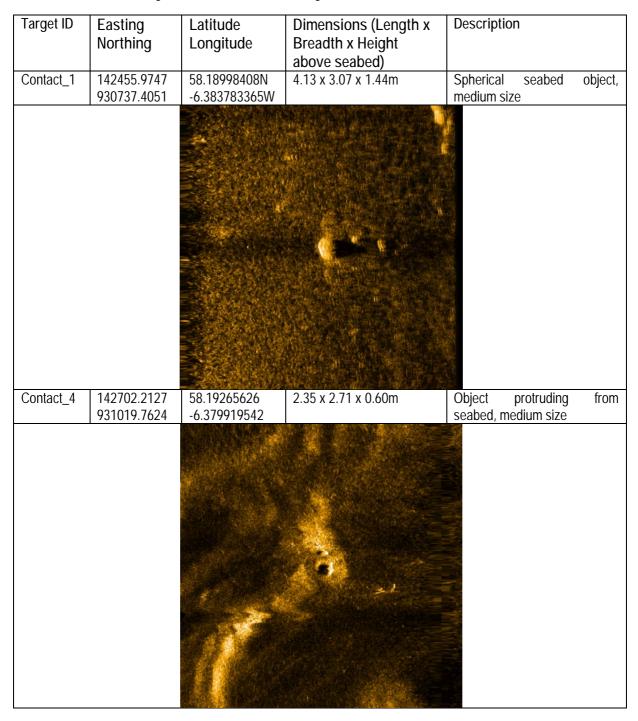
A5006_SSS	_12				
Position (E/N)	Position (WGS84)	Dimensions (Length x Breadth x Height above seabed)	Surrounding Depth (Chart Datum)	Least Depth (Chart Datum)	Remarks
142638 930761	58 11 25.10N 006 22 50.56W	40.2 x 8.3 x 0.5m	8-10m	8.06m	Area of Debris extending 20m south from suspected mooring block



# 9.5.4 Area 4 Significant Sidescan Sonar Targets

Multiple side-scan sonar targets were detected in area 4, which is likely to be as a result of the proximity of the fabrication yard and the use of the bay in oil rig construction in the past. These lesser targets are detailed in Table 2.

Table 2 - Side-scan sonar target information for Area 4, Glumaig Harbour





Target ID	Easting Northing	Latitude Longitude	Dimensions (Length x Breadth x Height above seabed)	Description
Contact_5	142641.7578 930985.5027	58.1923142 -6.380906951	6.25 x 2.27 x 0.42m	Object protruding from seabed, medium size
			<b>\</b>	
Contact_6	142700.5724 931005.9204	58.19253135 -6.379932076	2.89 x 1.08 x 1.51m	Object protruding seabed, medium size



Target ID	Easting Northing	Latitude Longitude	Dimensions (Length x Breadth x Height above seabed)	Description
Contact_7	142516.0448 931021.93	58.19256707 -6.383079123	4.45 x 3.29 x 0.63m	Medium sized object
Contact_8	142548.8441 930792.3708	58.19053049 -6.382269256	3.53 x 2.84 x 1.90m	Object protruding from seabed, medium size



Target ID	Easting Northing	Latitude Longitude	Dimensions (Length x Breadth x Height above seabed)	Description
Contact_9	142656.7771 931075.2364	58.19312655 -6.380751341	2.53 x 1.17 x 1.18m	Object protruding from seabed, small in size
Contact_10	142645.0343 931076.898	58.19313458 -6.380952324	4.05 x 1.14 x 0.62m	Object protruding from seabed, small in size



Target ID	Easting Northing	Latitude Longitude	Dimensions (Length x Breadth x Height above seabed)	Description
Contact_11	142768.876 931113.2904	58.1935327 -6.378892252	6.07 x 3.73 x 1.26m	Area of suspected debris with possible wreck prow
Contact_12	142638.7785 930761.328	58.19030496 -6.380709879	2.19 x 1.36 x 0.71m	Box-shaped object in debris field, medium size



Target ID	Easting Northing	Latitude Longitude	Dimensions (Length x Breadth x Height above seabed)	Description
Contact_15	142513.5845 931077.8499	58.19306641 -6.383182637	4.71 x 3.54 x 1.96m	Rock outcrop or boulder protruding from seabed, large in size
		, Y <b>A</b> ,		
		Le la company		
Contact_16	142673.1181 930602.4573	58.1889023 -6.379952128	7.75 x 0.50 x 0.30m	Large linear object, possibly a pipe, with pier cross brace shown
Contact_18	142496.3577 930723.9815	58.18988744 -6.383083737	14.95 x 7.61 x 0.86m	Large protruding object, probably outcropping rock



Target ID	Easting Northing	Latitude Longitude	Dimensions (Length x Breadth x Height above seabed)	Description
				ì



Mosaicked as a whole, the side-scan sonar survey of area 4 shows the dredged box in the centre of the harbour clearly, and highlights outcroppings of rock around the edges. The long, linear scour marks which can be seen in the bathymetry are also shown well Figure 24.

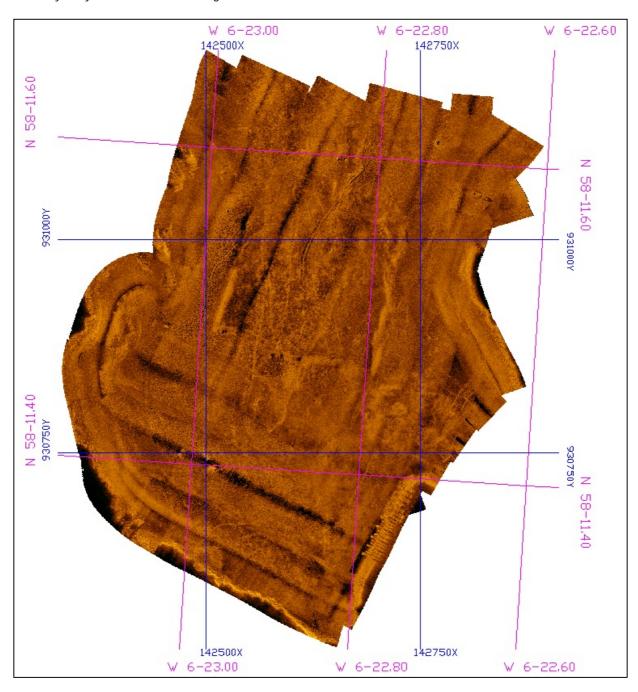


Figure 24 - Mosaicked side-scan sonar data for Area 4, Glumaig Harbour

The backscatter data collected in Area 4 suggests varying sediment types through the harbour Figure 25. On the western side at the inlet near Arnish Sheds there is a patch of high backscatter, suggesting a harder substrate in this patch than in the surrounding area. Fanning out from the inlet there is another patch with a higher backscatter than the surrounding area, which supports the idea drawn from the multibeam bathymetry that it is a patch of dredging spoils that has spread out over time.



The edges of the dredged box in the centre of Glumaig Harbour show up as bright lines on the backscatter data as a result of their steep sloping sides. The backscatter around the edges of the harbour is generally higher than in the centre, with numerous patches of rock outcropping seen and again steeply sloping edges. This data ties in well with the side-scan sonar survey.

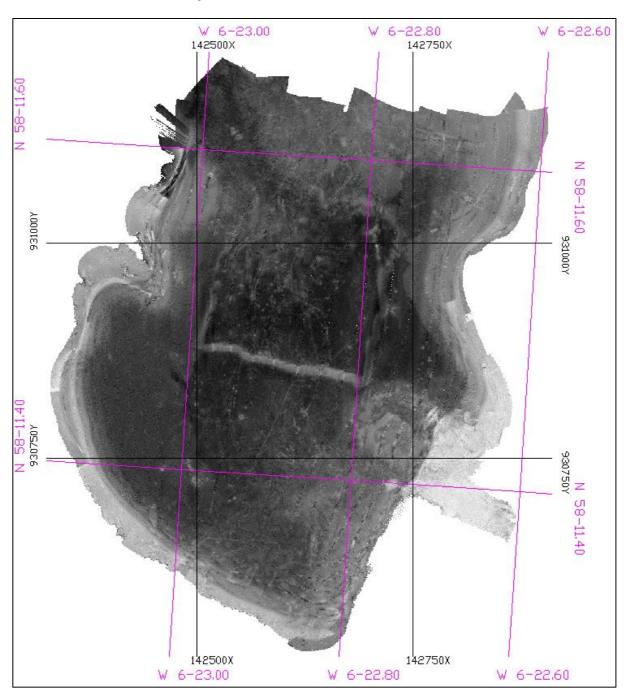


Figure 25 - Backscatter data from the multibeam system for Area 4, Glumaig, showing areas of differing sediment type (brighter colour corresponds with higher backscatter)



#### 9.6 Area 5 Inner Section

The inner section of Area 5, including all the previously described areas, had a depth range of 2.62m above Chart Datum to 16.90m below Chart Datum.

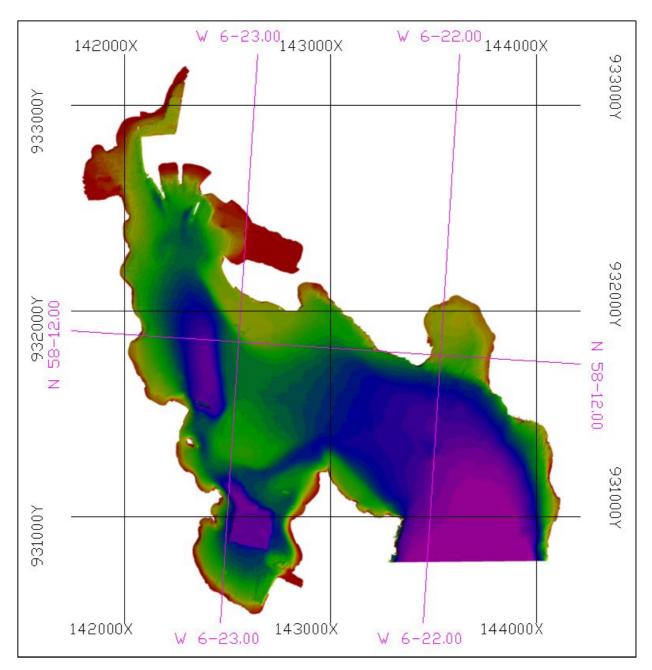


Figure 26 - TIN image generated from 1m gridded soundings showing the extents of Area 5 Inner

The magnetometer survey shows a linear magnetic anomaly running approximately north-south, shown in blue in Figure 27. An anomaly of a similar strength can be seen in the northern section of the survey. This could be a continuation of the previously described anomaly but is also very likely to have been influenced by the proximity of the dock wall and other structures that may have affected the background magnetic field strength.

The orientation of the linear anomaly ties in with the underlying geological structure in the area, with banding within the Lewisian gneiss and Tertiary basaltic dykes also lying in this direction<sup>5</sup>.

-

<sup>&</sup>lt;sup>5</sup> Barnes, R. GeoloGIS Report 2013/01 'Geological information for Stornoway Harbour'.



Two dipole magnetic anomalies can be seen on the west side of the harbour, shown in Figure 27 by the patches of red adjacent to blue. In conjunction with the bathymetric data and backscatter data, it can be stated that these are two known and charted wrecks. The westernmost wreck is thought to be the steel steamship Alabama <sup>6</sup>, and the wreck to the east is thought to be the coal hulk Portugal<sup>7</sup>. Details on these wrecks can be seen in Table 4.

To the west of Arnish Point, another magnetic anomaly was detected that can be attributed to an object on the seabed. This has been included in Wreck Report A5006\_SSS\_13 as it represents that detected wreck, the shape and size being similar to that of the boiler of a steamship, several of which are reported to have been wrecked in the area.

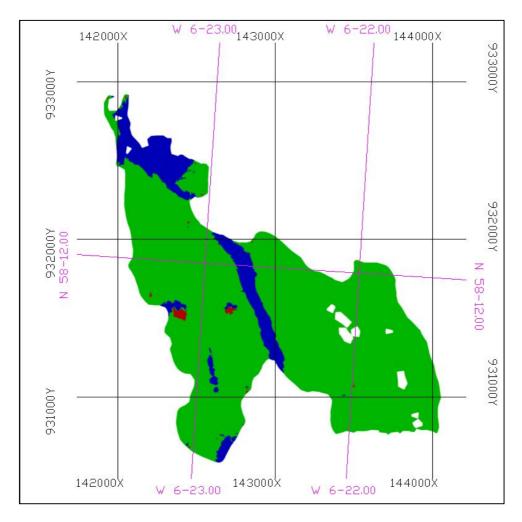


Figure 27 - TIN image generated from 2m sorted data showing background magnetic field strength with anomalies in blue (negative) and red (positive), showing the extents of the magnetometer survey

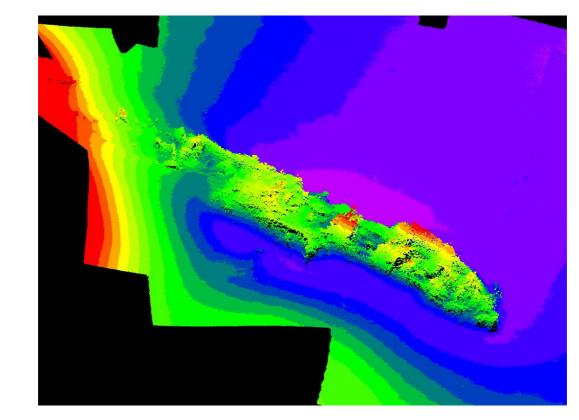
<sup>&</sup>lt;sup>6</sup> http://canmore.rcahms.gov.uk/en/site/102827/details/alabama+seid+rocks+stornoway+lewis+north+minch/

<sup>&</sup>lt;sup>7</sup> http://canmore.rcahms.gov.uk/en/site/102828/details/portugal+arnish+point+stornoway+lewis+north+minch/



Table 3 - Information related to wrecks and seafloor objects apparent in the inner part of Area 5

Position (E/N)	Position (WGS84)	Dimensions (Length x Breadth x Height above seabed)	Surrounding Depth (Chart Datum)	Least Depth (Chart Datum)	Remarks
142369 931549	58 11 51.38N 006 23 6.22W	112.5 x 15.2 x 5.0	13-14m	3.25m	Thought to be the wreck of the Alabama. Very broken but still a substantial wreck with significant height.

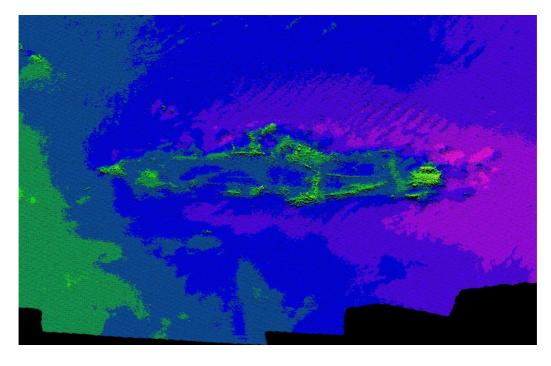




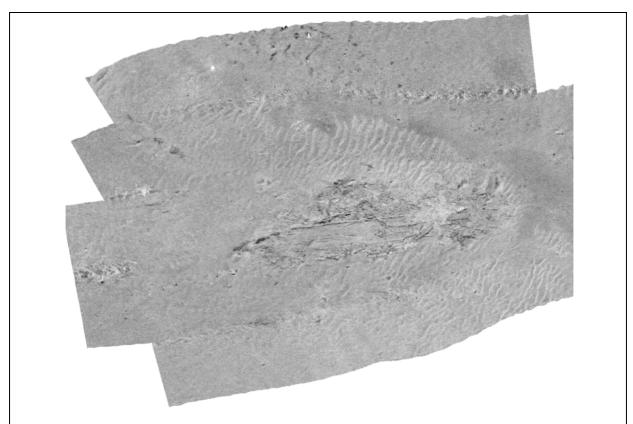




Position (E/N)	Position (WGS84)	Dimensions (Length x Breadth x Height above seabed)	Surrounding Depth (Chart Datum)	Least Depth (Chart Datum)	Remarks
142712 931566	58 11 52.63N 006 22 45.32W	71.5 x 12.7 x 0.5m	8-9m	7.46m	A very dispersed wreck debris field thought to be related to the known wreck Portugal (Charted)

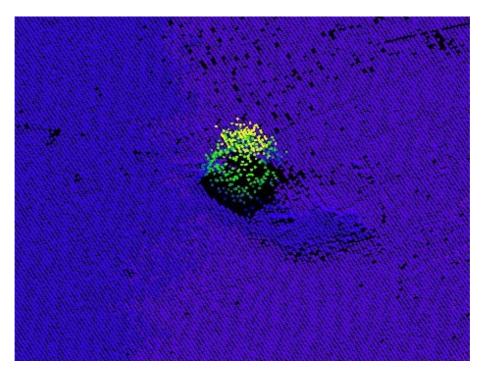




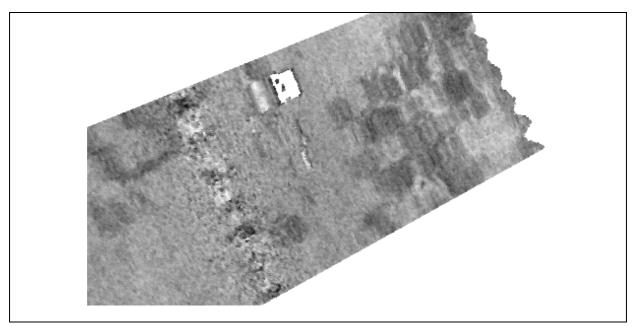




Position (E/N)	Position (WGS84)	Dimensions (Length x Breadth x Height above seabed)	Surrounding Depth (Chart Datum)	Least Depth (Chart Datum)	Remarks
143494 931080	58 11 38.59N 006 21 55.64W	4.4 x 3.9 x 3.1m	14-15m	10.64m	This magnetic contact correlates with this block feature detected on the seafloor East of Arnish Point. There is a charted Foul close north of this location. The block could possibly be associated with the ruined tower on Arnish Point.









The backscatter data in Area 5 outwith the 4 sub-areas already described was split into sections by day for processing and presentation, with sections from this shown below. In Mol Sandwick, a central area of reduced backscatter was seen to be present, suggesting that the sediment around the edges of the bay is coarser and harder Figure 28. A number of small objects can be seen in the area of higher backscatter, which are likely to be boulders or moorings / fish keeps.

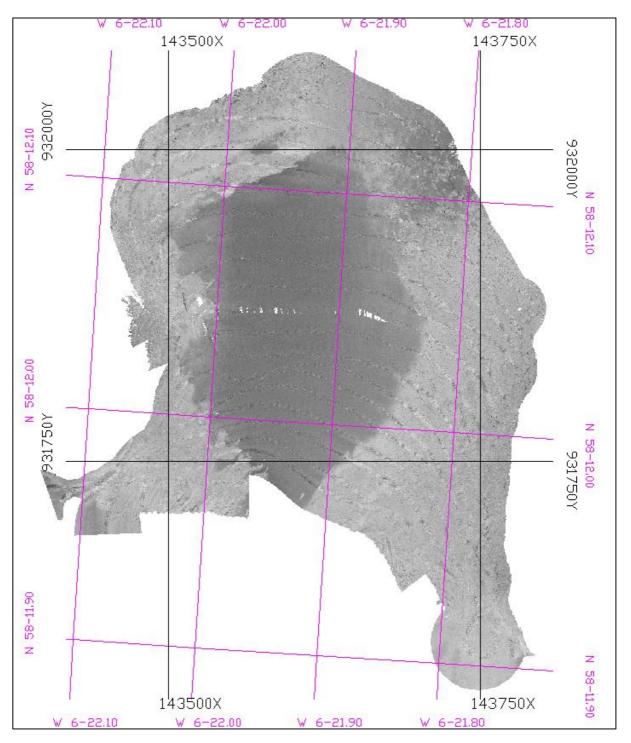


Figure 28 - Backscatter data from the multibeam system for Mol Sandwick, within Area 5 Inner, showing areas of differing sediment type (brighter colour corresponds with higher backscatter)



Backscatter data from along the western side of the harbour shows the shipwreck at 142369 931549 (59 11 51.38N 006 23 6.22W) clearly within a large patch of sediment with reduced backscatter. This suggests that the shipwreck rests within an area of finer sediment. Channels can be seen along the north-west edge of the area, showing as areas of higher backscatter.

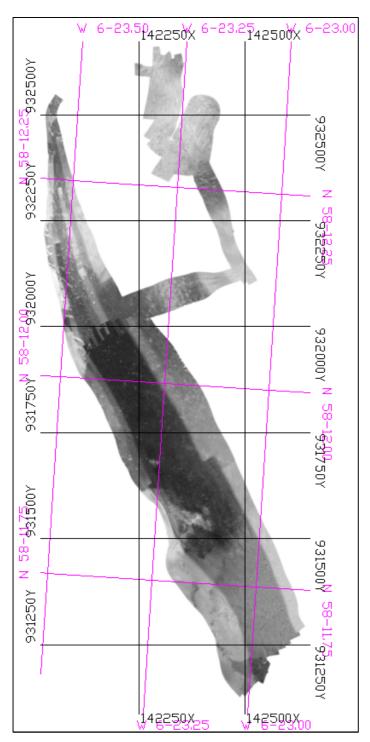


Figure 29 - Backscatter data from the multibeam system for 22<sup>nd</sup> February (western side of harbour from end of No. 1 Pier in the north to the entrance of Glumaig Harbour in the south) within Area 5 Inside, showing areas of differing sediment type (brighter colour corresponds with higher backscatter)



The central portion of the harbour shows a largely uniform sediment type across much of the southern part of the area Figure 30. A patch of what appears to be finer sediment can be seen in the north-west corner. Running along a line orientated north-west south-east through the site of the wreck at 142712 931566 (58 11 52.63N 006 22 45.32W) there is a patch of ripples which measure around 2.5m in wavelength from peak to peak, indicating a mobile substrate.

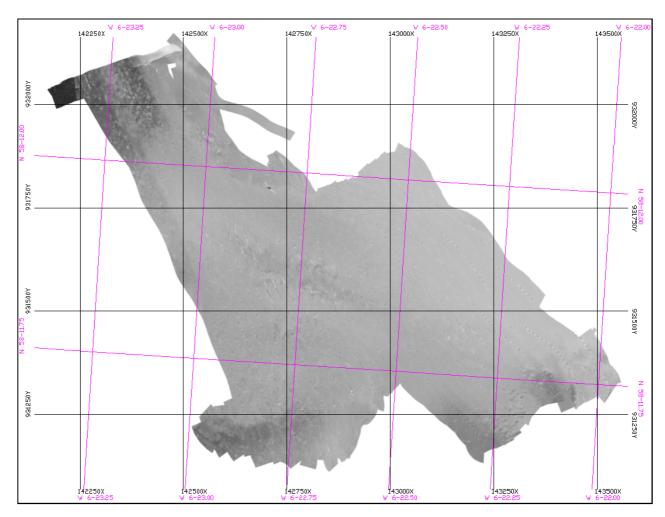


Figure 30 - Backscatter data from the multibeam system for 25<sup>th</sup> February (centre of the harbour from Goat Island in the north down to Glumaig Harbour in the south) within Area 5 Inside, showing areas of differing sediment type (brighter colour corresponds with higher backscatter)



The area running along the western side of the harbour from Goat Island down to Arnish Point shows several patches of finer sediment interspersed throughout the area. A patch of possible outcropping rock can be seen just north of 143500 931250 in Figure 31, with a large area of sediment finer than the surroundings to the south of this. Another area of finer sediment can be seen at the entrance to Mol Sandwick.

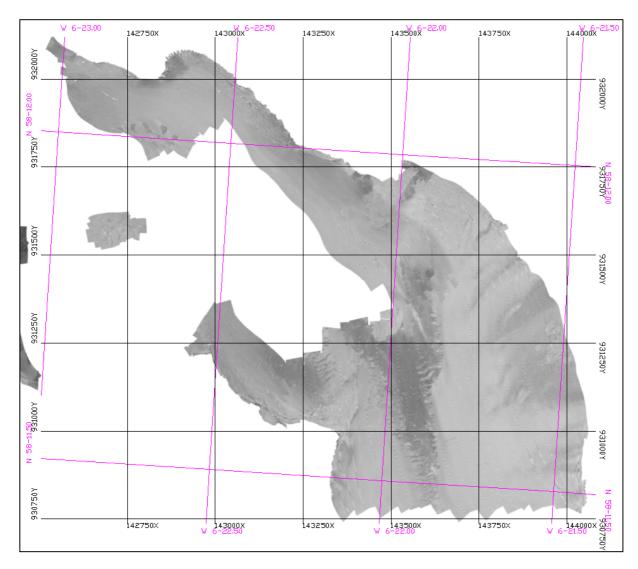


Figure 31 - Backscatter data from the multibeam system for 26<sup>th</sup> February (eastern side of the harbour from Goat Island in the north to Arnish Point in the south) within Area 5 Inside, showing areas of differing sediment type (brighter colour corresponds with higher backscatter)



#### 9.7 Area 5 Outer Section

The depths in the outer section of Area 5 extended from 2.20m above Chart Datum to 45.78m below Chart Datum, the greatest depths experienced in the survey. In the deepest areas to the south of the survey, several pock marks can be seen on the seabed, measuring up to 30m across. These may be as a result of escaping gas from under the seabed. The geological report of the surrounding area states that gas blanking was seen in seismic data outside Stornoway Harbour<sup>8</sup>, supporting the idea that gas could be escaping in this part of the survey area. Alternatively, this could be evidence of historical wartime activity.

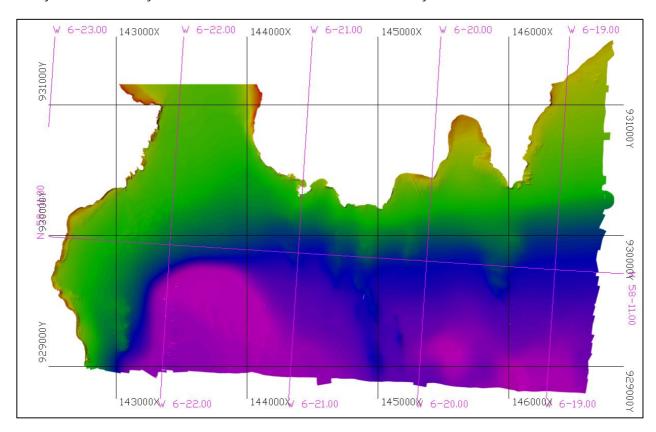


Figure 32 - TIN image generated from 1m gridded data showing the extents of Area 5 Outer

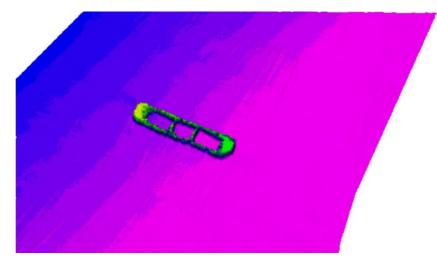
<sup>&</sup>lt;sup>8</sup> Barnes, R. 2013. GeoloGIS Report 2013/01 'Geological information for Stornoway Harbour'.

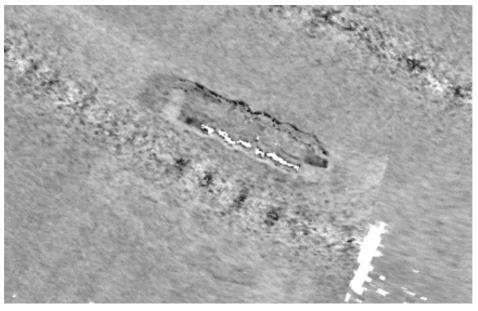


Two wrecks were identified in the outer part of Area 5, the details of which can be seen in Table 5.

Table 4 - Information relating to wrecks in the outer part of Area  $5\,$ 

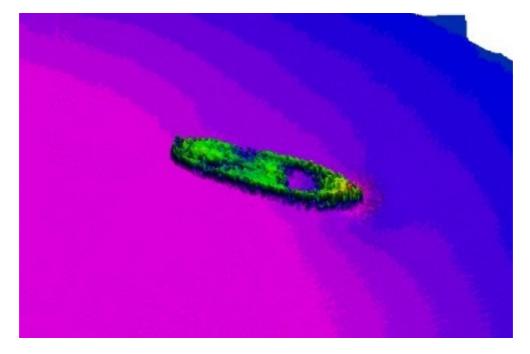
Position (E/N)	Position (WGS84)	Dimensions (Length x Breadth x Height above seabed)	Surrounding Depth (Chart Datum)	Least Depth (Chart Datum)	Remarks
142871 930027	58 11 3.33N 006 22 29.51 W	25.5 x 5.3 x 1.8m	16-17m	13.54m	Medium sized barge like structure with significant height above the seabed.



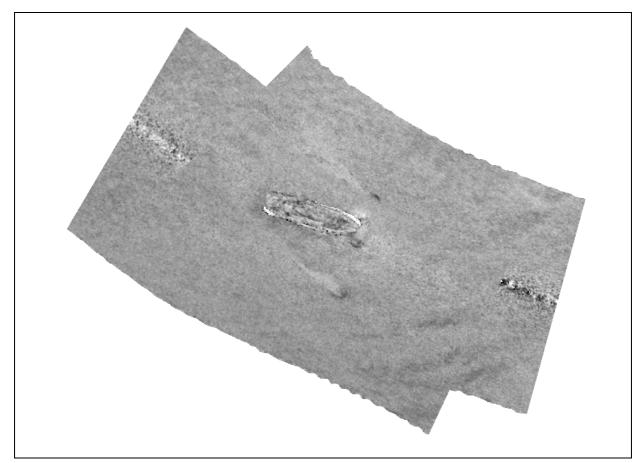




Position (E/N)	Position (WGS84)	Dimensions (Length x Breadth x Height above seabed)	Surrounding Depth (Chart Datum)	Least Depth (Chart Datum)	Remarks
144620 929950	58 11 4.53N 006 20 42.38W	30.0 x 6.5 x 2.3m	26-27m	22.91m	Medium sized intact wreck. Well decomposed.









The backscatter data for the outer part of Area 5 was processed in two parts. The north-east section Figure 33 shows an area of lower backscatter located within an inlet, which appears as a dark patch, probably representing a patch of finer sediment.

Also in this small inlet, ripples in the sand can be seen with a wavelength of approximately 0.5m, showing that in this area the substrate is mobile. Around the northern edges of this area rocky outcropping can be seen. Extending down from 145250 930500 an outfall can be seen, with the armour stone protecting it visible. In the west of the area, corresponding with the centre of the channel into the inner harbour, a fan shaped indentation can be seen, which is also apparent in the bathymetric data.

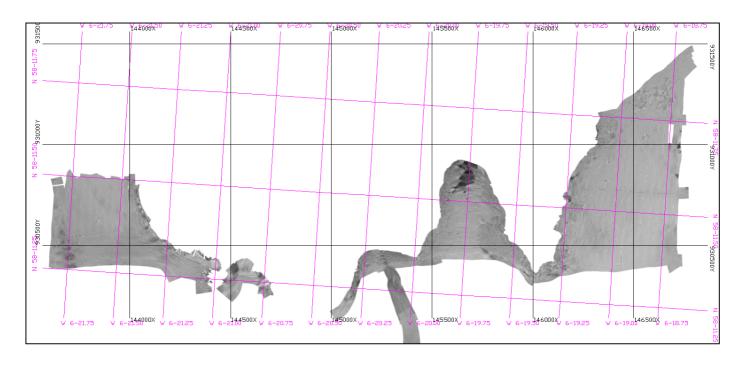


Figure 33 - Backscatter data from the multibeam system for the north-east part of the outer part of Area 5, showing areas of differing sediment type (brighter colour corresponds with higher backscatter)



The southern section of the outer part of Area 5 shows a linear area of higher backscatter in the centre, which corresponds with a raised ridge seen in the bathymetry Figure 34. This is likely to be outcropping rock. Closer to the shore, on the western and northern edges, areas of lower backscatter can be seen, which are likely to correspond with coarser sediment fringed by outcropping rock. Within these areas patches of low backscatter can be seen which are likely to be finer sediments. Numerous scours can also be seen.

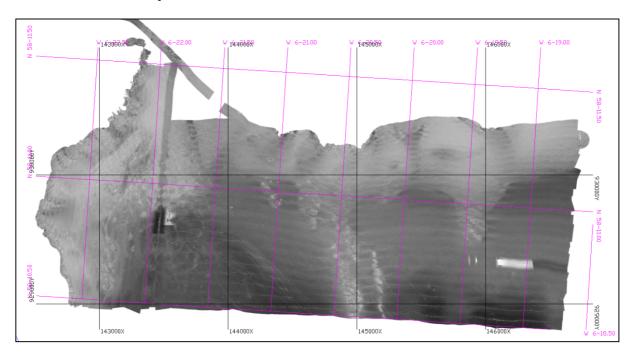


Figure 34 - Backscatter data from the multibeam system for the southern section of the outer part of Area 5, showing areas of differing sediment type (brighter colour corresponds with higher backscatter)



#### 10. Survey Vessel

The 8.4m fibreglass catamaran Remote Sensor was used to carry out all aspects of this survey. Remote Sensor is road towable and can be either slipway-launched or craned into the water. Remote Sensor is certified Cat III by the Maritime and Coastguard Agency for work up to 20nm offshore, carrying up to 6 persons.



Figure 35 - Survey vessel Remote Sensor with multibeam sonar and towed sensors deployed

Remote Sensor has a central moon pool to allow the multibeam sonar to be easily deployed and recovered. In addition the vessel has a large aft deck and a stern roller, which allows other survey sensors to be both stored and deployed.

The vessel was launched in Stornoway Harbour from the slipway in the grounds of Lews Castle at the start of the survey, and kept moored in the harbour for the duration of survey works. This allowed equipment to be kept mobilised on to the vessel so that survey works could be started promptly and efficiently each day regardless of tidal state. In addition it resulted in minimal transit times to different parts of the survey area. At the end of the survey operations the vessel was recovered from the same slipway.



#### 11. Survey Standards

The Hydrographic survey is considered complete to International Hydrographic Organisation Special Order standard, with a Full Sea Floor Search being achieved as per IHO publication S44, Table 1. A representation of the section of interest within that document is shown in Table 6:

Table 5 - Taken from IHO publication S44, Table 1, showing requirements of a Special Order Survey

Order	Examples of Typical Areas	Horizontal Accuracy (95% Confidence Level)	Depth Accuracy for Reduced Depths (95% Confidence Level)	100% Bottom Search	System Detection Capability	Maximum Line Spacing
Special	Harbours, berthing area and associated critical channels with minimum under keel clearances	2m	a = 0.25m b = 0.0075	Compulsory	Cubic features > 1m	Not applicable as 100% search compulsory

The error limits for depth accuracy are calculated by introducing the values listed in (X) for a and b into the formula  $\pm \sqrt{[a^2+(b^*d)^2]}$ , where:

- a constant depth error, i.e. the sum of all constant errors
- b\*d depth dependent error, i.e. the sum of all depth dependent errors
- b factor of depth dependent error
- d depth9

The line spacing used for side-scan sonar, magnetometer and sub-bottom profiler surveys are considered well suited to achieve a full understanding of the environment. The multibeam system and associated backscatter was shown on numerous instances to be capable of detecting objects far smaller than the 1m cubic features specified for a Special Order survey.

#### 12. Personnel

The following personnel were involved during the survey:

NAME	POSITION
C.D. Thomson	Party Chief (Hydrographic)
G.T. Campbell	Hydrographic Surveyor
G.J. Campbell	Quality Control
B. Connell	Survey Assistant
E.J. Stacey	Graduate Hydrographic Surveyor

<sup>&</sup>lt;sup>9</sup> IHO 2005. Publication M-13 'Manual on Hydrography'. Chapter 1, Pages 9-10.



### Annex A Drawing Record

A5006

AutoCAD	🚰 A5006_Area 1_SBP.dwg		
Drawings	🚰 A5006_Area 2_SBP.dwg		
	A5006_Area 3_SBP.dwq		
	A5006_Area 4_SBP.dwg		
	A5006_Area 4_SSS.dwg		
	A5006_Area 5 Inside_Magn	etometer dwa	
		-	
	A5006_Area 5 Inside_MBES	_	
	A5006_Area 5 Outside_MBE	:S.dwg	
	A5006_Area_1_MBES.dwg		
	A5006_Area_2_MBES.dwg		
	🚰 A5006_Area_3_MBES.dwg		
	🚰 A5006_Area_4_MBES.dwg		
	A5006_Overview_MBES.dw	q	
DDE E''		_	-
PDF Files	AS006_Area 1_SBP-Viewport 1.pdf	A5006_Area 4_SSS-Viewport 5.pdf	AS006_Area_1_MBES-Viewport 2.pdf
	A5006_Area 1_SBP-Viewport 2.pdf	AS006_Area 5 Inside_Magnetometer-Viewport 1.pdf	A5006_Area_2_MBES-Viewport 1.pdf
	A5006_Area 2_SBP-Viewport 1.pdf A5006_Area 2_SBP-Viewport 2.pdf	A5006_Area 5 Inside_Magnetometer-Viewport 2.pdf A5006_Area 5 Inside_Magnetometer-Viewport 3.pdf	A5006_Area_2_MBES-Viewport 2.pdf A5006_Area_3_MBES-Viewport 1.pdf
	A5006_Area 3_SBP-Viewport 1.pdf	A5006_Area 5 Inside_Magnetometer-Viewport 4.pdf	AS006_Area_3_MBES-Viewport 2.pdf
	A5006_Area 3_SBP-Viewport 2.pdf	A5006_Area 5 Inside_MBES-Viewport 1.pdf	A5006_Area_3_MBES-Viewport 3.pdf
	A5006_Area 3_SBP-Viewport 3.pdf	A5006_Area 5 Inside_MBES-Viewport 2.pdf	5 A5006 Area_4 MBES-Viewport 1.pdf
	A5006_Area 4_SBP-Viewport 1.pdf	A5006_Area 5 Inside_MBES-Viewport 3.pdf	5 A5006_Area_4_MBES-Viewport 2.pdf
	5 A5006_Area 4_SBP-Viewport 2.pdf	A5006_Area 5 Inside_MBES-Viewport 4.pdf	5 A5006_Area_4_MBES-Viewport 3.pdf
	5 A5006_Area 4_SBP-Viewport 3.pdf	A5006_Area 5 Outside_MBES-Viewport 1.pdf	5 A5006_Area_4_MBES-Viewport 4.pdf
	5 A5006_Area 4_SBP-Viewport 4.pdf	🔁 A5006_Area 5 Outside_MBES-Viewport 2.pdf	5.pdf A5006_Area_4_MBES-Viewport 5.pdf
	🔁 A5006_Area 4_SBP-Viewport 5.pdf	🔁 A5006_Area 5 Outside_MBES-Viewport 3.pdf	A5006_Overview_MBES-Viewport 1.pdf
	🔁 A5006_Area 4_SSS-Viewport 1.pdf	🔁 A5006_Area 5 Outside_MBES-Viewport 4.pdf	A5006_Overview_MBES-Viewport 2.pdf
	🔁 A5006_Area 4_SSS-Viewport 2.pdf	🔁 A5006_Area 5 Outside_MBES-Viewport 5.pdf	A5006_Overview_MBES-Viewport 3.pdf
	🔁 A5006_Area 4_SSS-Viewport 3.pdf	🔁 A5006_Area 5 Outside_MBES-Viewport 6.pdf	
	🔁 A5006_Area 4_SSS-Viewport 4.pdf	A5006_Area_1_MBES-Viewport 1.pdf	
Sidescan	A5006_Stornoway_Harbour	_Area_4.TFW	
Sonar	A5006_Stornoway_Harbour	_Area_4.tif	
Masaic			



Images of	a5006_30028-ch1.jpg	a5006_10035-ch1.jpg	A5006_10006-CH1.jpg	■ A5006_40046-CH1.jpg	■ A5006_40017-CH1.jpg	A5006_20022-CH1.jpg
Sub Bottom	a5006_30027-ch1.jpg	A5006_10034-CH1.jpg	A5006_10004-CH1.jpg	A5006_40045-CH1.jpg	A5006_40016-CH1.jpg	A5006_20021-CH1.jpg
	a5006_30026-ch1.jpg	A5006_10033-CH1.jpg	A5006_10003-CH1.jpg	■ A5006_40044-CH1.jpg	A5006_40015-CH1.jpg	■ A5006_20020-CH1.jpg
Profiling	a5006_30025-ch1.jpg	A5006_10032-CH1.jpg	A5006_10002-CH1.jpg	A5006_40043-CH1.jpg	A5006_40014-CH1.jpg	A5006_20019-CH1.jpg
lines	a5006_30024-ch1.jpg	A5006_10031-CH1.jpg	A5006_10001-CH1.jpg	A5006_40042-CH1.jpg	■ A5006_40013-CH1.jpg	■ A5006_20018-CH1.jpg
	a5006_30023-ch1.jpg	A5006_10030-CH1.jpg	A5006_10005-CH1.jpg	■ A5006_40041-CH1.jpg	■ A5006_40012-CH1.jpg	■ A5006_20017-CH1.jpg
	a5006_30022-ch1.jpg	<b>S</b> A5006_10029-CH1.jpg	■ A5006_40069-CH1.jpg	■ A5006_40040-CH1.jpg	<b>S</b> A5006_40011-CH1.jpg	■ A5006_20016-CH1.jpg
	a5006_30021-ch1.jpg	A5006_10028-CH1.jpg	A5006_40068-CH1.jpg	A5006_40039-CH1.jpg	A5006_40010-CH1.jpg	■ A5006_20015-CH1.jpg
	a5006_30020-ch1.jpg	A5006_10027-CH1.jpg	A5006_40067-CH1.jpg	A5006_40038-CH1.jpg	A5006_40009-CH1.jpg	A5006_20014-CH1.jpg
	a5006_30019-ch1.jpg	A5006_10026-CH1.jpg	A5006_40066-CH1.jpg	A5006_40037-CH1.jpg	A5006_40008-CH1.jpg	A5006_20013-CH1.jpg
	a5006_30018-ch1.jpg	A5006_10025-CH1.jpg	A5006_40065-CH1.jpg	🔤 A5006_40036-CH1.jpg	A5006_40007-CH1.jpg	🔤 A5006_20012-CH1.jpg
	a5006_30017-ch1.jpg	SA5006_10024-CH1.jpg	A5006_40064-CH1.jpg	A5006_40035-CH1.jpg	A5006_40006-CH1.jpg	A5006_20011-CH1.jpg
	a5006_30016-ch1.jpg	SA5006_10023-CH1.jpg	A5006_40063-CH1.jpg	A5006_40034-CH1.jpg	A5006_40005-CH1.jpg	SA5006_20010-CH1.jpg
	a5006_30015-ch1.jpg	A5006_10022-CH1.jpg	A5006_40062-CH1.jpg	A5006_40033-CH1.jpg	A5006_40004-CH1.jpg	A5006_20009-CH1.jpg
	a5006_30014-ch1.jpg	A5006_10021-CH1.jpg	A5006_40061-CH1.jpg	A5006_40032-CH1.jpg	A5006_40003-CH1.jpg	A5006_20008-CH1.jpg
	a5006_30013-ch1.jpg	A5006_10020-CH1.jpg	A5006_40060-CH1.jpg	A5006_40031-CH1.jpg	A5006_40002-CH1.jpg	A5006_20007-CH1.jpg
	a5006_30012-ch1.jpg	A5006_10019-CH1.jpg	A5006_40059-CH1.jpg	A5006_40030-CH1.jpg	A5006_40001-CH1.jpg	A5006_20006-CH1.jpg
	a5006_30011-ch1.jpg	A5006_10018-CH1.jpg	A5006_40058-CH1.jpg	A5006_40029-CH1.jpg	A5006_20034-CH1.jpg	A5006_20005-CH1.jpg
	a5006_30010-ch1.jpg	A5006_10017-CH1.jpg	A5006_40057-CH1.jpg	A5006_40028-CH1.jpg	A5006_20033-CH1.jpg	A5006_20004-CH1.jpg
	a5006_30009-ch1.jpg	A5006_10016-CH1.jpg	A5006_40056-CH1.jpg	A5006_40027-CH1.jpg	A5006_20032-CH1.jpg	A5006_20003-CH1.jpg
	a5006_30008-ch1.jpg	A5006_10015-CH1.jpg	A5006_40055-CH1.jpg	A5006_40026-CH1.jpg	A5006_20031-CH1.jpg	A5006_20002-CH1.jpg
	a5006_30007-ch1.jpg	A5006_10014-CH1.jpg	A5006_40054-CH1.jpg	A5006_40025-CH1.jpg	A5006_20030-CH1.jpg	A5006_20001-CH1.jpg
	a5006_30006-ch1.jpg	A5006_10013-CH1.jpg	A5006_40053-CH1.jpg	A5006_40024-CH1.jpg	A5006_20029-CH1.jpg	△5006_10035A-CH1.jpg
	a5006_30005-ch1.jpg	A5006_10012-CH1.jpg	A5006_40052-CH1.jpg	A5006_40023-CH1.jpg	A5006_20028-CH1.jpg	
	a5006_30004-ch1.jpg	A5006_10011-CH1.jpg	A5006_40051-CH1.jpg	A5006_40022-CH1.jpg	A5006_20027-CH1.jpg	
	a5006_30003-ch1.jpg	A5006_10010-CH1.jpg	A5006_40050-CH1.jpg	A5006_40021-CH1.jpg	A5006_20026-CH1.jpg	
	a5006_30002-ch1.jpg	A5006_10009-CH1.jpg	A5006_40049-CH1.jpg	A5006_40020-CH1.jpg	A5006_20025-CH1.jpg	
	a5006_30001-ch1.jpg	A5006_10008-CH1.jpg	A5006_40048-CH1.jpg	A5006_40019-CH1.jpg	A5006_20024-CH1.jpg	
	A5006_10036-CH1.jpg	A5006_10007-CH1.jpg	A5006_40047-CH1.jpg	A5006_40018-CH1.jpg	A5006_20023-CH1.jpg	
Report	A5006_Stornoway F	Harbour_Report of S	Survey			
GeoloGIS	GeoloGIS_report20	13-01 Issue1.pdf				
Background		- '				
Geological						
Report						



## Annex B Horizontal and Vertical Positioning System Precision

A5006

Horizontal and Vertical Positioning System Precision

#### **Topographic Measurement**

Trimble R7 Geodetic grade GPS Receivers

	HORIZONTAL ACCURACY	VERTICAL ACCURACY
STATIC POINT POSITIONING	±5mm + 0.5ppm RMS	±5mm + 1ppm RMS

#### **Dynamic Positioning Precision**

TRIMBLE MS860 Geodetic grade GPS Receiver and Heading system, utilising RTK corrections.

	HORIZONTAL ACCURACY	VERTICAL ACCURACY
REAL TIME KINEMATIC	±10mm + 1ppm RMS	±20mm + 1ppm RMS

All horizontal positions in the survey are referred to OSGB and have used the OSTN 02 model to transform WGS84 positions obtained from GPS observations.



#### **Data Processing Procedures**

#### **Multibeam Processing Stages**

Sonar Control 2000 software was used to control the MBES system during the data gathering phase.

Data was logged in HYPACK HYSWEEP software.

After data gathering the data was post processed in HYPACK MBMax where the following stages of processing were undertaken:

- Navigation data was processed.
- Motion Sensor data was examined and edited as required.
- Tidal data was examined and edited as required
- Automatic filtering of the data was carried out.
- Individual lines of MBES sounding data were manually edited.
- Processed files were loaded into Fledermaus visualisation and editing software and fully quality assured before being unloaded back to Hypack.
- The data was gridded at an appropriate post spacing for the scale of plot requested by the client. This was exported to AutoCAD for presentation.
- The data was contoured at 0.5m intervals in Hypack and exported to AutoCAD.

#### Side-Scan Sonar Processing Stages

The side-scan data was processed in Chesapeake SonarWiz5 software where the following procedures were undertaken:

- Import of all side-scan xtf and sdf files into Chesapeake SonarWiz Software
- Lines were replayed to assess the bottom tracking, gain and time variable gain settings and these were adjusted as necessary to ensure optimal representation of the sonar record.
- All lines were examined for any significant sonar contacts.
- Any detected sonar contacts were sized, heighted and checked to see that they had been adequately
  depicted in the bathymetric survey. No contacts were detected by sidescan that were not adequately
  depicted in the multibeam survey.
- A sonar mosaic was prepared to show the seabed type over the entire survey area.
- A Sidescan Sonar Mosaic of the entire area was carried out. This was prepared in Chesapeake sonarWiz and AutoCAD and rendered in AutoCAD dwg format.



#### **Magnetometer Processing Stages**

The magnetometer data was recorded in Hypack. The Hypack Single Beam Editor was used for processing, with the following procedures undertaken:

- Import of all HSX files into Single Beam Editor software
- Lines replayed and data spikes examined and edited as necessary to ensure optimal representation of the magnetometer record
- Lines examined for any significant magnetic anomalies
- Data exported in xyz format
- 3D rendering and magnetic field strength contours generated and plotted in AutoCAD dwg format

#### **Sub-bottom Profiler Processing Stages**

The sub-bottom profiler data was collected and processed using Chesapeake SonarWiz Software.

- SEG-Y data was imported into the software
- Frequency filtering, gain and time-variable gain settings were adjusted to ensure that the best possible picture of the sub-bottom data was available to the user
- Each individual horizon was digitised
- An xyz of the thickeness between the seabed and each horizon was prepared and exported to McCarthy Taylor System LSS 3D modelling software
- LSS was used to prepare isopach xyz and to export isopach dxf of the sediment thickness
- A drawing file was prepared in AutoCAD to show the sediment thickness detected during the survey

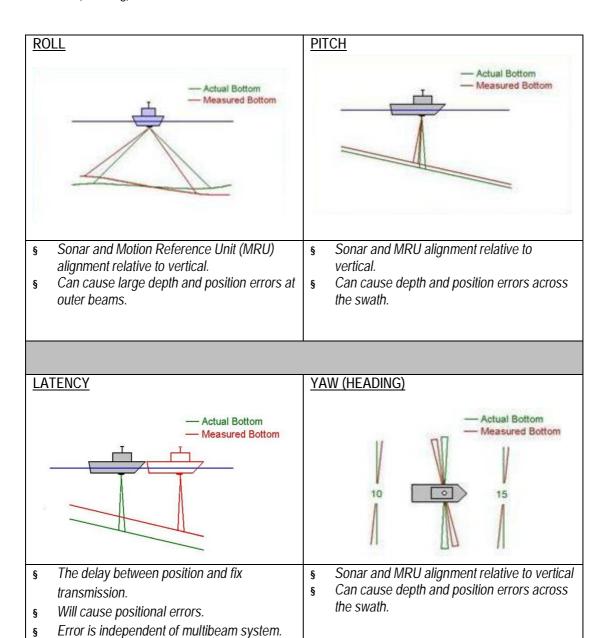


#### Multibeam Echosounder Calibration

Patch tests are tests which are performed after initial equipment installation, and periodically thereafter as well as if sensors are modified, to quantify any residual biases from the initial system alignment.

During this calibration series, four separate tests must be performed to determine residual alignment biases for:

- § Roll offset
- § Position Time Delay (Latency)
- § Pitch Offset
- § Yaw (Heading) Offset



#### Calibration



Patch Testing was performed on 19<sup>th</sup> February 2013 and periodically thereafter. There were areas of steep slopes in addition to flat seabed, allowing a very effective calibration to be carried out on the entire system.

Latency	-0.40
Pitch	-1.00
Roll	-0.60
Yaw	5.50

These values, obtained at the start of the survey, remained valid throughout the duration of survey operations.



#### Standard Disclaimer

- 1. All client-supplied data is taken on trust as being accurate and correct, and the sub contractor cannot be held responsible for the quality and accuracy of that data set.
- 2. Geophysical interpretation of bathymetry and sonar is based on an informed opinion of the supplied data, and is subject to inherent errors out with the control of the interpretational hydrographer or geophysicist, which include but are not limited to GPS positioning errors, navigation busts, data quality, assumed speed velocity sediment profiles in the absence of Geotechnical data, sub bottom profile pulse width, and induced scaling errors therein associated with seismic signature. Seabed geomorphology and sub-seabed geology should be further investigated by visual or intrusive methods.
- 3. The limits of this survey are defined by the data set; out with the survey limits are not covered at any level by the sub contractor.
- 4. The data is accurate at the time of data acquisition, the sub contractor cannot be held responsible for environmental changes, and the client by accepting this report accepts that the environment of the seabed is subject to continuous change, that items of debris, hard contacts etc. may move, appear, be relocated or removed, thickness of surficial sediment change out with the knowledge of the sub contractor and they will not be held responsible for such actions at any level.





**Geological Report** 

# Geological information in support of a marine survey of Stornoway Harbour, Lewis

GeoloGIS Report 2013/01

Issue1: 9<sup>th</sup> April 2013

GeoloGIS Ltd Kirklee Westruther Scottish Borders TD3 6NE

© GeoloGIS 2013

Client: Aspect Land & Hydrographic Surveys Ltd

Unit 1, Thornhouse Business Centre

Ballot Road, Irvine,

Ayrshire KA12 0HW, Scotland

GeoloGIS Report 20	13/01: Issue 1.	Date of Issue: 09 April 2013	
Geological information in support of a marine survey of Stornoway Harbour, Lewis			
Author:	R P Barnes	05/04/2013	
Checked:	Aspect Surveys Ltd.		
Classification:	Commercial in Confidence		
Distribution:	Aspect Land & Hydrographic Surveys Ltd		

This report has been prepared by GeoloGIS Ltd. with all reasonable skill, care and diligence within the resources devoted to it by agreement with the client, Aspect Land & Hydrographic Surveys Ltd. and by completion of works as instructed prior to or varied as agreed during the course of the works

The report has been prepared to provide general information to assist the client in the interpretation of the marine survey data for the site, it is not a substitute for detailed ground investigations necessary to validate any interpretation and no decision should be taken based on the content of this report alone.

This report is for the exclusive use of Aspect Land & Hydrographic Surveys Ltd; no warranties or guarantees are expressed or should be inferred by any third parties. This report may not be relied upon by other parties without written consent from GeoloGIS Ltd.

GeoloGIS Ltd. disclaims any responsibility to Aspect Land & Hydrographic Surveys Ltd and others in respect of any matters outside the agreed scope of the work or reliance upon this report except as expressly provided for above.

#### **Revision Table:**

Issue:	Date:	Revision details:
Draft 1	20/02/2013	Preliminary report draft for client review
Issue 1	09/04/2013	Re-issued as Issue 1

GeoloGIS Ltd. is registered in Scotland (No. SC379433) at Kirklee, Westruther, Berwickshire TD3 6NE

GeoloGIS Report 2013/01	Geological information for Stornoway Harbour	Commercial in Confidence
Issue 1	Page i of 18	Date: 09/04/2013

#### **EXECUTIVE SUMMARY**

This report, commissioned by Aspect Land & Hydrographic Surveys Ltd., provides an overview of the geology of Stornoway Harbour and adjacent areas in support of their acquisition and interpretation of a new survey of the sea bed morphology and sub-sea bed geology.

The report describes the geology of the bedrock and superficial deposits in and around the harbour as far as can be determined from available information sources. However, mapping is only available at very small scale and therefore is generalised and not accurate. Major gaps occur in the available information, in particular there is a data gap offshore in the near-shore zone including most of Stornoway Harbour, and a lack of mapping or modern description of the Quaternary deposits in the onshore or near shore area.

The succession in the harbour area is summarised as follows:

Deposit	Composition		
Onshore Quaternary and recent deposits	A discontinuous but complex mixture of till, sand and gravel, peat and wind blown sand with submerged peat, clay and beach deposits in the near shore area		
Offshore Quaternary and recent deposits	Sea bed sediments passing from gravelly sand to slightly gravelly sandy mud; probably resting on rockhead or glacial deposits in the inner harbour but with a silty mud wedge (Annie sequence) rapidly thickening offshore to 20 m or more in the outer harbour, overlying a variable thickness of till.		
Highly	Highly irregular rockhead surface		
Tertiary intrusive dyke rocks	Basalt/dolerite in NW-trending dykes		
Jurassic rocks (thin sandstone and lipersist into the outermost part of the h	mestone overlain by mudstone) occur offshore and may arbour although it is thought unlikely		
Permo-Triassic rocks: Stornoway Formation	Reddish brown conglomerate with subordinate sandstone and sparse lenses or beds of siltstone and mudstone with cornstone; dipping 10-45°		
Unconformity or fault contact			
Proterozoic or Archaean age 'Lewisian' metamorphic rocks of	Banded gneiss with pods of basic gneiss, variably deformed by a cataclastic fabric, with basic or granitic intrusions.		

The Stornoway Formation rests unconformably on the Lewisian gneiss beneath Stornoway and much of the harbour area, but in the west of the harbour the two groups of rocks are juxtaposed by a fault (or zone of faults); evidence of fracturing suggests that additional faults occur in the harbour area within outcrop of the Stornoway Formation.

The literature review undertaken for this work has been limited; a more detailed study of published and unpublished information may add significantly to the information presented.

It is recommended that a survey of the coastal exposures is completed in conjunction with the marine surveys. This will provide detailed data to support the interpretation of the marine surveys and will add considerably to information regarding the character of the deposits / rocks and structural features in the area.

GeoloGIS Report 2013/01	Geological information for Stornoway Harbour	Commercial in Confidence
Issue 1	Page i of 18	Date: 09/04/2013

# **INDEX**

Figure 8

Figure 9

1	Introduction			. ]
	1.1	Infor	mation used for this study	. ]
2	Bee	drock		. 3
	2.1	Lewi	sian metamorphic rocks	۷.
	2.1	.1	Structure	. 6
	2.1	.2	Geotechnical characteristics	. 5
	2.2	Perm	no-Triassic rocks: Stornoway Formation	. 6
	2.2	.1	Structure	. 7
	2.2	.2	Geotechnical characteristics	. 7
	2.3	Juras	ssic strata	. 9
	2.4	Terti	ary intrusive rocks	. 9
	2.4	.1	Geotechnical characteristics	1(
3	Qu	aterna	ary deposits	1(
	3.1	Quat	ernary deposits onshore / nearshore	1(
	3.2	Quat	ernary deposits offshore	1]
	3.2	.1	Till	13
	3.2	.2	Annie sequence	13
	3.2	.3	Sea bed sediments	13
4	Su	nmar	y	15
5	Re	ferenc	ees	16
	Ap	pendi	x 1 Offshore borehole log and sea bed samples	16
L	IST O	F FIG	GURES	
Fi	igure 1	S	Stornoway Harbour plan	
F	igure 2	. (	Offshore bedrock map showing the general disposition of the main bedrock units	
F	igure 3		Onshore bedrock geology	
Fi	igure 4	S	Structural elements of the Lewisian and Permo-Triassic rocks	
F	igure 5	S	Sketch map of the Stornoway area from Stevens (1914)	
F	igure 6	i A	Airborne magnetic data for Lewis and the Minch	
F	igure 7	′ (	Offshore Quaternary map with log of borehole 78/4 and cross-section	

GeoloGIS Report 2013/01	Geological information for Stornoway Harbour	Commercial in Confidence
Issue 1	Page ii of 18	Date: 09/04/2013

Generalised thickness of the Quaternary succession offshore

Offshore seabed sediment map

#### 1 Introduction

This report, commissioned by Aspect Land & Hydrographic Surveys Ltd. provides a review of the geological composition and structure of Stornoway Harbour, Lewis, (Fig 1). The following chapters describe the geology of the bedrock and superficial deposits in and around the harbour as far as can be determined from available information sources.

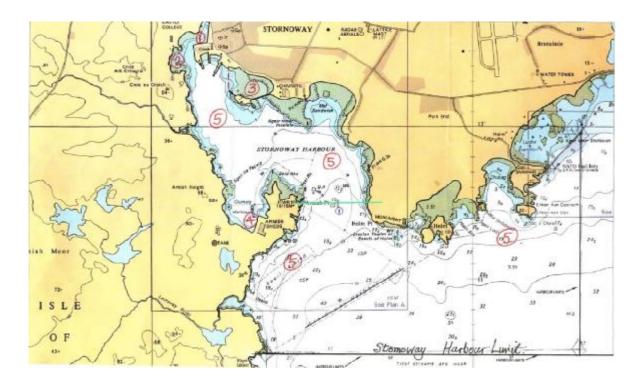


Figure 1. Stornoway Harbour plan

#### 1.1 Information used for this study

This information used in the compilation of this report is listed in Table 1

The available map products are very small scale and cannot be regarded as accurate. A data gap exists in the near shore area between the onshore and offshore mapping. Much of the area of Stornoway Harbour falls within this data gap.

Onshore, no mapping is available for the superficial deposits and no published descriptions are available; the bedrock mapping was compiled at 1:100,000 scale using information from survey mapping and various academic and research studies, presents a generalised interpretation with low detail and accuracy.

Offshore, mapping at 1:250,000 scale has been compiled from marine geophysical surveys in the 1960's and 70's and seabed boreholes and grab samples. The latter are sparsely distributed such that only two samples occur within the area of Stornoway Harbour and the nearest borehole is c. 4 km outside of the harbour (Figure 2)

GeoloGIS Report 2013/01	Geological information for Stornoway Harbour	Commercial in Confidence
Issue 1	Page 1 of 18	Date: 09/04/2013

Focus	Document	Scale	Date
Onshore geological mapping	Lewis & Harris north map (bedrock only)	100 k	1981
Boreholes onshore and near shore	Shallow site investigation boreholes as available at the BGS onshore 'GeoIndex' (Figure 2)		various
Onshore geology description	Memoir: Geology of the Outer Hebrides (Fettes et al. 1992)		1992
Offshore sea bed map	Lewis Sheet 58N 08W: Sea bed sediments	250 k	1989
Offshore superficial deposits map	Lewis Sheet 58N 08W: Quaternary	250 k & 1:1 million	1989
Offshore bedrock geology map	Lewis Sheet 58N 08W: Solid geology	250 k & 1:1 million	1989
Offshore geology description	Offshore regional report: Malin- Hebrides sea area (Fyfe et al. 1993)		1993

Table 1: data sources used for this report

GeoloGIS Report 2013/01	Geological information for Stornoway Harbour	Commercial in Confidence
Issue 1	Page 2 of 18	Date: 09/04/2013

#### 2 BEDROCK

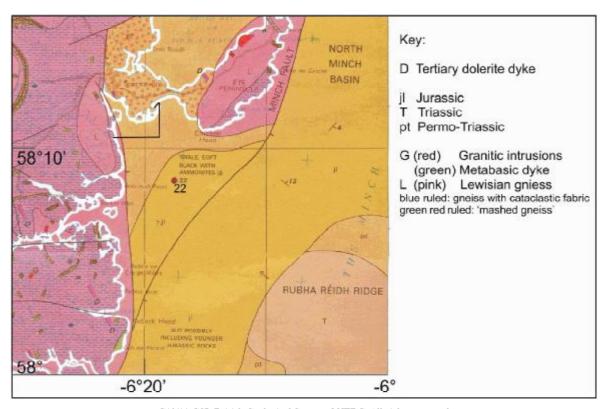
Stornoway Harbour lies in the inner part of a natural inlet, the shape of which is closely related to the underlying bedrock structure (Figure 2).

Excluding the Arinis peninsula, the straight western side of the inlet marks the outcrop of a fault zone that juxtaposes Permian and/or Triassic rocks on the east against the Precambrian metamorphic rocks of the Lewisian Complex on the west.

Beneath the bay, and most of Stornoway itself, the Permo-Triassic rocks rest unconformably on the metamorphic rocks; the unconformity surface is likely to be irregular but is broadly west- or north-west dipping at an angle of up to 45° such that it crops out on the west side of the Eye Peninsula.

The faults in the vicinity of Stornoway lie within the footwall block of the substantial NNE-trending Minch Fault, this generally forming the western margin of the Mesozoic North Minch Basin (Figure 2). Offshore, probably beyond the harbour limit, the Permo-Triassic rocks pass up into ammonite-bearing mudstone of lower Jurassic age.

All of these rocks are cut by a swarm of north-west trending Tertiary basaltic dykes



 $C12\!/11\text{-}CSL$  British Geological Survey. ©NERC. All rights reserved

Figure 2: Offshore bedrock map showing the general disposition of the main bedrock units that crop out onshore and offshore (see also Figure 3).

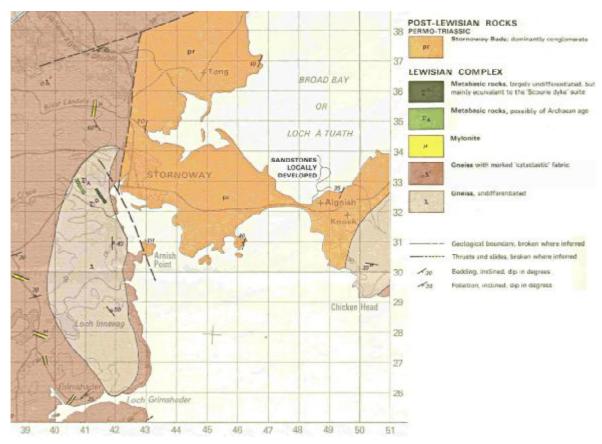
Reproduced from British Geological Survey 1:250,000 scale Sheet 58N 08W (Lewis), Solid Geology, by permission of the British Geological Survey. ©NERC. All rights reserved

GeoloGIS Report 2013/01	Geological information for Stornoway Harbour	Commercial in Confidence
Issue 1	Page 3 of 18	Date: 09/04/2013

#### 2.1 Lewisian metamorphic rocks

The Lewisian Complex is the name given to the oldest rocks exposed in the UK, representing ancient (Proterozoic and/or Archaean age, c. 2 billion year old) continental crust. The complex is composed of predominantly quartzo-feldspathic gneiss with a wide variety of basic and ultrabasic components. These were formed by a long and complex history of metamorphism and deformation from a range of igneous rocks, including granitoids and basic to ultrabasic dykes, along with some sedimentary rocks.

These rocks are predominantly coarse-grained, banded gneiss, commonly with dark lenses. Metasedimentary enclaves, occurring on a range of sizes from kilometres to metres in length may include calcareous and graphitic gneiss, quartzite and rare marble together with flaggy biotite-rich garnetiferous gneiss. Closely associated with the metasedimentary rocks are basic and ultrabasic rocks of igneous origin, some of which commonly preserve a well-developed layering. Dioritic and granitic intrusions that largely post-date the formation of the gneiss foliation occur locally. These were succeeded by a widespread swarm of basic dykes (the 'Scourie' dykes) that are now evident as dark brown or black, parallel-sided layers varying in thickness from a few centimetres to several tens of metres. Subsequent deformation caused folding of the gneiss foliation and the dykes and, where most intense, has brought the dykes into concordance with the gneiss foliation. Towards the end of this later deformation, another suite of granite and pegamatite veins was emplaced.



C12/11-CSL British Geological Survey. ©NERC. All rights reserved

Figure 3: Onshore bedrock map (north to top, grid squares 1 km)

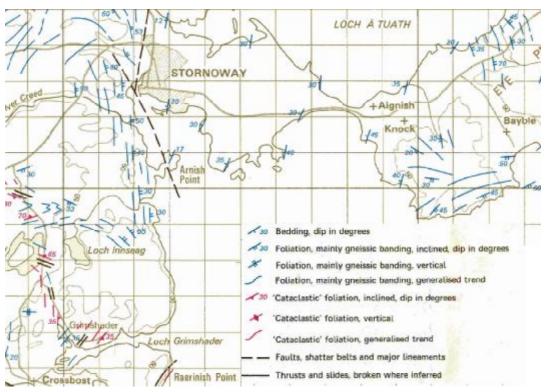
Reproduced from Institute of Geological Sciences 1:100,000 scale Sheet Lewis and Harris (north), by permission of the British Geological Survey. ©NERC. All rights reserved

GeoloGIS Report 2013/01	Geological information for Stornoway Harbour	Commercial in Confidence
Issue 1	Page 4 of 18	Date: 09/04/2013

These rocks were subsequently further modified by development of a planar fissility that becomes more evident eastwards in the Outer Hebrides, culminating in a broad zone of deformation termed the Outer Hebrides Thrust Zone. This is mainly seen as a cataclastic fabric of varying intensity within the gneiss, generally sub-parallel to the gneiss banding. However, where more intense areas of structurally isotropic micobreccia and cataclasite (termed 'mashed gneiss') were formed as a result of multiple fracturing events. Locally, more highly deformed rocks occur as layers of highly fissile of flaggy phyllonite or mylonite, and where deformation has caused localised melting, psuedotachylite seen as intricate vein networks of black glass within the gneiss.

The Lewisian rocks that crop out to the west of Stornoway Harbour (figures 3 & 4) are mapped as 'gneiss with a cataclastic fabric' surrounding a large enclave of gneiss. A few meta-basic dykes are indicated inland but the low density cannot be taken dykes as representative because many may not have been mapped. Narrow outcrops of mashed gneiss and mylonite are shown locally west of Stornoway but others may occur.

A detailed though somewhat dated description of the Lewisian rocks in the vicinity of Stornoway is provided by Stevens (1914).



C12/11-CSL British Geological Survey. ©NERC. All rights reserved

Figure 4: Structural elements of the Lewisian and Permo-Triassic rocks in the Stornoway area (north to top, grid 1 km)

Reproduced from 'Lewis and Harris (north) 1:100,000 Structure' map in Fettes et al. (1992), by permission of the British Geological Survey. ©NERC. All rights reserved

GeoloGIS Report 2013/01	Geological information for Stornoway Harbour	Commercial in Confidence
Issue 1	Page 5 of 18	Date: 09/04/2013

#### 2.1.1 Structure

The layering or banding within the Lewisian gneiss west of Stornway Harbour appears to be consistently striking a few degrees west of north with dip in the range from 30-60° east (Figure 4). No information is available as to the orientation of the cataclastic foliation in this area, although it may, where well-developed, form the primary fissility within the rock.

The only faults shown on the small scale maps are those forming the boundary between the Permo-Triassic and Lewisian rocks, although even these may be generalised; many other fault structures are likely to be present.

The western bounding fault passes through the Arinis peninsula where its nature and location can be closely constrained by bedrock exposure. Although mapped at small scale as a single fault, features in the coastline of the peninsula suggest that several closely spaced fault strands are present.

Aerial photography (e.g. Google Earth) shows many linear features within the Lewisian outcrop to the west and south of the harbour including marked sets in NNW-, NNE- and ENE-striking orientations often hundreds of metres in length suggesting minor faults or related fracture zones in these orientations

#### 2.1.2 Geotechnical characteristics

Little detailed information is available regarding the geotechnical characteristics of the Lewisian rocks. It would be expected to be medium strong, to strong, variably banded and foliated, but it may vary depending critically on the precise nature of the rock, the degree of alteration and weathering and on the discontinuity characteristics including the intensity, orientation and continuity of the cataclasic fabric and fracture sets.

However, extensive bedrock exposure, both natural and in quarries, is available in the vicinity of Stornoway that would provide a considerable amount of information of relevance to engineering design through appropriate field investigation.

### 2.2 Permo-Triassic rocks: Stornoway Formation

A thick succession of reddish brown conglomerate and sandstone is preserved on the east of Lewis in the vicinity of Stornoway and underlies most of Stornoway Harbour, resting unconfomably on, or faulted against, the Lewisian rocks (Figures 3 & 4). Termed the Stornoway Formation, these rocks are interpreted from regional considerations to be of Permian or Triassic age (e.g. Steel & Wilson, 1975).

The conglomerate consists mainly of rounded to sub-rounded clasts of gneiss and vein quartz; typically these range up to 20 cm in size but they include some boulders up to 80 cm. The deposits form units of three types:

- Sheet deposits within which boulders may locally define crude bedding but generally the sorting is very poor and the deposits are massive, clast supported with siltstone matrix; they rarely pass up into cross-laminated sandstone.
- Lenticular units with a marked basal erosion surface, within which the conglomerate is commonly cross-stratified (sets up to 1.5 m thick) generally passing up into laminated or cross-laminated sandstone.

GeoloGIS Report 2013/01	Geological information for Stornoway Harbour	Commercial in Confidence
Issue 1	Page 6 of 18	Date: 09/04/2013

• Small-scale, lenticular channel-fill conglomerate, usually finer grained and well-sorted with intraformational clasts, passing laterally and vertically into sandstone with thin lenses of siltstone

These units are interlayered with much thinner units composed primarily of upward thinning and fining ssequences of sandstone, siltstone and mudstone. Cornstone may be developed within the upper part of cycles within which rooted or burrowed horizons may be recognised, reflecting periods of subaerial exposure and soil development.

The conglomerate is well-exposed in coastal sections north-east of Stornoway and on the Eye Peninsula. The interbedded sequence of sandstone, siltstone, mudstone and cornstone crops out on the east side of Stornoway Harbour, between Melbost and Aignish and near Shandwick.

Further detailed descriptions of the Stornoway Formation are provided by Steel & Wilson (1975) and references therein.

#### 2.2.1 Structure

From Figure 4, the dip-direction of the Stornoway Formation is consistently WNW, the dip of the strata lies between 30-40° over much of the eastern and central part of the outcrop but declines to 10° close to the north-western bounding fault in the vicinity of Stornoway.

As noted above, the western bounding fault passes through the Arinis peninsula where, although mapped at small scale as a single fault, features in the coastline of the peninsula suggest that several closely spaced fault strands are present within the Permo-Triassic rocks (Figure 5).

Aerial photography (e.g. Google Earth) provides an insight into the fracture patterns within the rocks of the Stornoway Formation in the east side of the harbour where a wave cut platform occurs in the coastal outcrop.

In the inner part of the harbour, exposure in the south-west side of Eilean na Gobhail appears to reveal a conspicuous zone of persistent, relatively closely spaced, NW-trending fractures. More widely spaced fractures in the same orientation occur on the headland of Rubha Thuilm and to a lesser extent on the tip of the Airinis peninsula suggesting that a zone of NW-trending fractures, perhaps associated with faulting is present along the axis of the harbour (Figure 5).

From the east side of Eilean na Gobhail southwards, for example around Rubha Thuilm and Eilean Thuilm, NNE- to ENE-trending fractures are variably well-developed. Between these locations there are breaks in exposure across two coastal embayments near Sandwick that could be related to NE-trending fracture zones or faults that, if they cross the putative axial fault, would pass either side of the Airinis peninsula to the south-west to terminate at the western bounding fault zone.

NNE-trending fractures are particularly well-developed in the foreshore either side of the narrow isthmus leading to the Eye Peninsula, extending up to 1 km onto the peninsula in the vicinity of Aignish. This fracturing, coupled with breaks in exposure across the isthmus and either side strongly suggests that faults may be present in this orientation.

Faulting in the Aignish section is confirmed by Stevens (1914, Figure 6) as follows:

'In the Agnish section are numerous gentle faults which have not disturbed the uniform dip of 45 degrees toward the north-west nor the edges of the strata. Only at the head of the little bay at Roisinish, whose veretical sides are fault planes, is extensive of complex faulting to be seen'

#### 2.2.2 Geotechnical characteristics

Geotechnical descriptions of the rocks that make up the Stornoway Formation are available in a few site investigation boreholes east of Stornoway.

GeoloGIS Report 2013/01	Geological information for Stornoway Harbour	Commercial in Confidence
Issue 1	Page 7 of 18	Date: 09/04/2013

A borehole c. 1 km north-west of Mealbost [NGR 145461 932602] proved peat to 2.1 m overlying 2.8 m of broken sub-angular to sub-rounded greyish gravel to cobbles thought possibly to be weathered to decomposed conglomerate. Between 4.9 m and the end of the borehole at 12 m, very weak, weathered greyish brown to dark reddish brown conglomerate is composed of gravel to cobbles with occasional boulders in slightly silty sand to fine gravel matrix. The core was very badly broken throughout.

At the eastern extremity of the harbour, several shallow boreholes located within a few tens of metres of the pier at Gob Shildinis provide records of the upper 6 m of the conglomerate as very weak to moderately strong, dark grey and dark red-brown, slightly weathered becoming fresh, gravel conglomerate, consisting of fine to coarse sub-rounded to sub-angular strong gneiss clasts set in a moderately weak cemented sand matrix; occasional to numerous rounded to sub-rounded gneiss cobbles'. In one borehole the top 2 m of the conglomerate was decomposed, being recorded as dark red brown and dark grey, medium to coarse gravel, cobbles and boulders interpreted as weathered, weakly cemented conglomerate

However, characterisation of the extensive coastal exposures within and on the east side of the harbour and on the Eye Peninsula would provide considerable information in support of site-specific investigations.

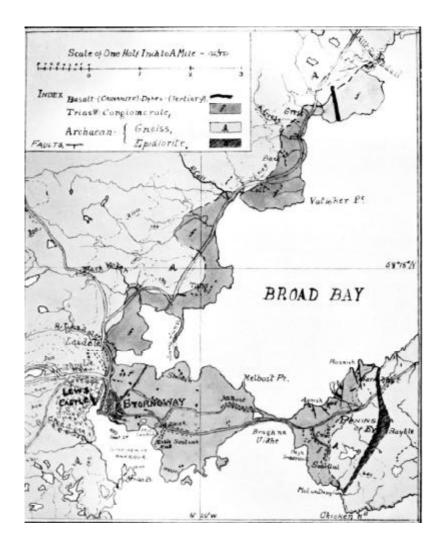


Figure 6: Sketch map of the Stornoway area from Stevens (1914)

GeoloGIS Report 2013/01	Geological information for Stornoway Harbour	Commercial in Confidence
Issue 1	Page 8 of 18	Date: 09/04/2013

#### 2.3 Jurassic strata

Jurassic strata overlie the Permo-Triassic rocks and crop out over much of the North Minch Basin. A succession up to 2500 m in thickness has been interpreted (Fyfe et al. 1993) from seismic surveys immediately adjacent to the east of the Minch Fault.

Jurassic strata are proved in offshore borehole 78/4 (location 22 on Figure 2) to occur within the footwall block of the Minch Fault but as mapped they do not extend as far west as Stornoway Harbour. However, this interpretation is based on fairly limited evidence and it is possible that, depending on the structure and rockhead height, these rocks may extend into the outer part of the harbour.

The basal part of the Jurassic succession within the North Minch Basin, the Broadford Beds Formation, consists of 'hard to very hard' white, blocky, medium-grained sandstone interbedded with firm homogeneous, pale grey mudstone. A c. 1 m thick bed of 'hard' white, crystalline limestone occurs at the top of the formation.

The overlying Pabba Shale Formation consists of 'moderately hard', medium to dark grey, blocky mudstone or silty mudstone with calcareous cement. In parts these are very calcareous and very micaceous and include lenses of fine- to coarse-grained quartz sand. This formation may have been sampled offshore of Stornoway in Borehole 78/4 (Appendix 1): rockhead was recorded at 55.77 m beneath which 14 m of strata are described as 'soft, poorly fissile, black shale or mudstone, calcareous, with abundant shell fragments and occasional ammonites'. The dip of bedding was measured at c. 17.5° (relative to the perpendicular to the borehole axis).

#### 2.4 Tertiary intrusive rocks

The Lewisian rocks are cut regionally by a swarm of broadly NW-trending basaltic dykes related to Tertiary magmatic centres in the west of Scotland.

The Tertiary dykes are not shown on the onshore bedrock map, although one is mapped on the offshore bedrock map cutting the Stornoway Formation on the north west coast of the Eye Peninsula (Figure 3).

Stevens (1914 & Figure 6) records that the dykes are numerous as follows:

'Three are seen near the western border of the conglomerate at Cuddy Point in the Castle grounds and one of these at least appears again at Arnish. There are two on the west end of Goat Island, one on the beach at Newton, two a mile north-east from Agnish, one of which may run across to Gress, reappearing with two others in Eye'.

He describes them as having a coarse- or fine-grained basaltic appearance with fine-grained chilled margins and 'botryoidal' weathering. Thickness varies from about 30 cm to > 2.5 m. They have usually baked the conglomerate on their margins, but 'stand up from the conglomerate and even the gneiss'.

Because the basaltic rock has a relatively high magnetic susceptibility these dykes often stand out as anomalies within magnetic survey data (e.g. Figure 6). To the east of Lewis in the Minch, a persistent NNW-trending anomaly is interpreted as a particularly large dyke, c. 1.1 km in width. Emplaced within the Permo-Triassic and Jurassic sedimentary rocks, the top of the dyke is thought to lie at a depth of 0.3 - 2 km.

A similar NNW-trending anomaly, although less persistent and less intense, passes through or close to Stornoway Harbour (Figure 6) suggesting that a significant dyke may also be present in this area, conceivably concealed at depth as the Minch dyke. However, Stevens (1914) records, three closely spaced basalt dykes near Lews Castle and a dyke on the Airinis peninsula (Figure 6) that may explain the anomaly or be the surface expression of a larger concealed dyke.

GeoloGIS Report 2013/01	Geological information for Stornoway Harbour	Commercial in Confidence
Issue 1	Page 9 of 18	Date: 09/04/2013

It is not possible from the available information to assess accurately the dip or continuity of the Tertiary dykes, although they are typically steeply dipping or vertical.

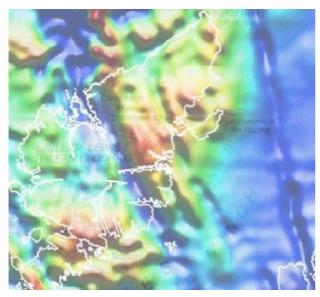


Figure 6

Airborne magnetic data for Lewis and the Minch showing NNW-trending anomalies probably due to basalt dykes.

Reproduced from BGS GeoIndex website by permission of the British Geological Survey. ©NERC. All rights reserved

C12/11-CSL British Geological Survey.  ${\tt @NERC}.$  All rights reserved

#### 2.4.1 Geotechnical characteristics

These relatively young igneous rocks are likely to be strong to very strong where fresh, black basalt or dolerite, although Stevens indicates that botryoidal (spherulitic) weathering is variably developed.

The discontinuity characteristics will be determined partly by the extent of any cooling fabrics, typically jointing developed perpendicular to the dyke walls and often orientated polygonally.

#### 3 QUATERNARY DEPOSITS

The Quaternary Period was a time of dramtic changes in climatic conditions and rapid changes in sea level. At times glaciation caused erosion with redeposition of those materials as till and sand and gravel and glaciomarine deposits that offshore may locally exceed 300 m in thickness. Interglacial periods were marked by accumulations of peat and marine or intertidal deposits that have continued to develop since the last phase of deglaciation, since which time wide areas onshore have also accumulated thick deposits of wind blown sand.

#### 3.1 Quaternary deposits onshore / nearshore

No systematic mapping or description of the Quaternary deposits in the onshore or nearshore area around Stornoway has been found, although the following description by Stevens (1914) testifies to a complex succession of Quaternary deposits onshore and near shore around Stornoway:

'The whole of the district is covered with till more or less thickly. Washed drift is found at Garabost, near which are layers of shell-bearing clay.... Marine clays with foraminifera have been

GeoloGIS Report 2013/01	Geological information for Stornoway Harbour	Commercial in Confidence
Issue 1	Page 10 of 18	Date: 09/04/2013

found in the area at considerable heights above sea level, and over all is a thick coat of peat.... Further, Mr Gibson found a submerged peat bed exposed during low ebbs in Mol Sandwick and there is another in the little inlet at Arnish at the edge of the conglomerate. Both bear the stumps of numerous small trees, chiefly birch, and the remains of leaves may be picked up from the peat. These seem most likely to be peat banks of interglacial times.... Wind blown sand builds the machar at Melbost, and similar deposits of some extent occur elsewhere in the island. The isthmus which connects the Peninsula of Eye to the main part of Lewis is formed by the coalescence of two magnificent examples of shingle bars thrown up from Broad Bay on one side and the Bragh nah Uidhe on the other and ponding up between them Loch Branahuie'.

Site investigation boreholes are available in the near shore harbour area at two locations:

In the inner part of the harbour between Esplanade Road and North Beach Quay the deepest of three site investigation boreholes recorded the following succession:

Tarmac to 0.15 m

'Filling: medium dense brown fine to coarse (silty clayey) SAND with much fine to coarse gravel' to 2.9 m

'Compact firm to coarse angular gravel with some fine to coarse sand and traces of ash possibly filling' to 3.8 m

'Compact sand and gravel' to the end of the borehole at 4.1 m

At the eastern extremity of the harbour, several shallow boreholes are located within a few tens of metres of the jetty at Gob Shildinis (note these records include sidescan sonar and hydrographic survey data of the seabed ). These record rockhead in conglomerate overlain by deposits of sand or gravel from 1.3 to 2.3 m thick, in places interlayered (beds 0.5 - 1.0 m), described as follows:

Sand: very dense, light grey-brown, slightly silty to silty, fine to coarse SAND with some to much rounded to sub-angular, fine to coarse gneiss gravel and occasional cobbles; many shell fragments throughout.

Gravel: medium to very dense dark grey and red-brown sandy fine to medium, sub-angular to sub-rounded gneiss GRAVEL; abundant shell fragments and occasional cobbles.

Farther inland, sparse site investigation records in Stornoway provide a few shallow boreholes proving significant thicknesses (in excess of 2 m) of till or peat locally, the latter resting on sand and gravel.

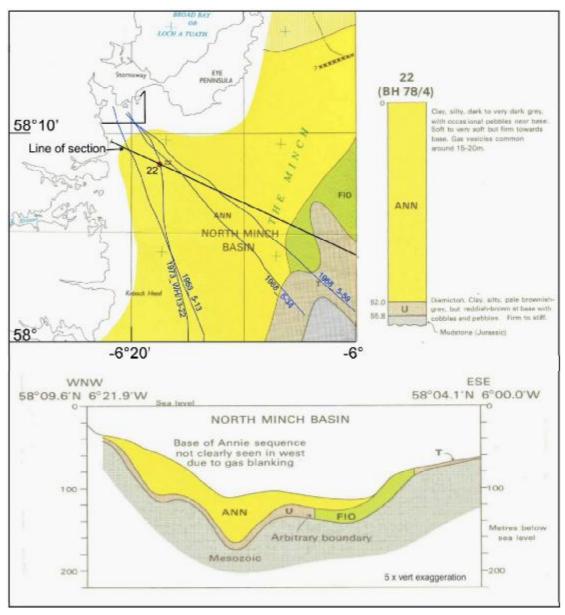
Numerous trial pit records and a few boreholes in the vicinity of Stornoway airport again record peat locally up to 2 m in thickness and, towards Broad Bay, a substantial thickness (in excess of 15 m) of sand (described as very loose to medium dense, silty, fine to medium sand with traces of shell fragments and sparse beds of sandy silt with organic debris).

#### 3.2 Quaternary deposits offshore

A thick succession of Quaternary (Pleistocene and Holocene) deposits is present in the offshore areas of the North Minch Basin and a complex stratigraphy identified and defined mainly from seismic investigations (e.g. Fyfe et al. 1993). Only one of these units, the 'Annie sequence' is present in the vicinity of Stornoway Harbour where it is thought to rest on a relatively thin layer of glacial till deposits (Figure 7).

Mapping of the Quaternary succession in the offshore are near Stornoway is based on a network of seismic lines, four of which come into the outer part of the harbour (Figure 8). Copies of the non-interpreted seismic records have been acquired for these lines.

GeoloGIS Report 2013/01	Geological information for Stornoway Harbour	Commercial in Confidence
Issue 1	Page 11 of 18	Date: 09/04/2013



C12/11-CSL British Geological Survey. ©NERC. All rights reserved

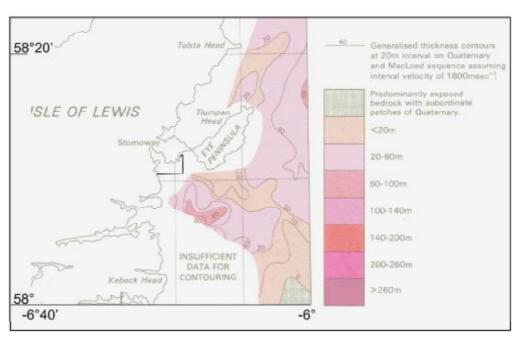
Figure 8: Extract from the offshore Quaternary map (BGS 1989a) with section of Borehole 78/4 (see also Appendix 1) and cross section along the line drawn on the map; the blue lines on the map show the traces of marine survey lines as numbered.

Reproduced from British Geological Survey 1:250,000 scale Sheet 58N 08W (Lewis), Quaternary Geology, by permission of the British Geological Survey. ©NERC. All rights reserved

GeoloGIS Report 2013/01	Geological information for Stornoway Harbour	Commercial in Confidence
Issue 1	Page 12 of 18	Date: 09/04/2013

#### 3.2.1 Till

The cross-section from the offshore Quaternary map (BGS 1989a, Figure 8) shows a continuous layer of till above rockhead and underlying the Annie sequence. The thickness is illustrated as 20 – 50 m but this may be diagrammatically exaggerated because in borehole 78/4 (location 22 on Figure 8) only two short sections of core, spanning less than 4 m of section and composed of clay or silty clay with pebbles and cobbles, are interpreted as till (borehole section on Figure 8 and Appendix 1).



C12/11-CSL British Geological Survey. ©NERC. All rights reserved

Figure 8: Generalised thickness of the Quaternary succession offshore

Reproduced from inset map at 1:500,000 scale on British Geological Survey 1:250,000 scale Sheet 58N 08W (Lewis), Quaternary Geology, by permission of the British Geological Survey. ©NERC. All rights reserved

#### 3.2.2 Annie sequence

The Annie sequence has an unconformable base, infilling hollows left by glacial erosion of the older parts of the Pleistocene succession. It is said to be clearly seismically differentiated by very fine seismic lamination with internal reflectors that drape the underlying topography.

Although it rarely exceeds 25 m in thickness, the Annie sequence fills a rockhead basin centred c. 13 km south-east of Stornoway to a depth of up to 90 m (Figure 8). Gas blanking is recorded in seismic data from this area

From figures 8 & 9 it is likely that mud of the Annie sequence extend into at least the outer part of Stornoway Harbour where it may reach 20 m or more in thickness.

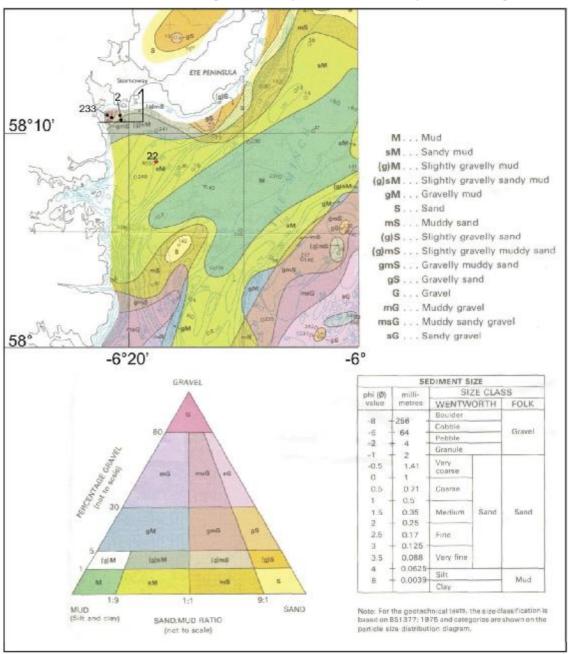
#### 3.2.3 Sea bed sediments

Mapping of the sea bed sediments (BGS 1989b, Figure 9) has been achieved mainly by grab sampling from the top 50 mm of sediment. Only two samples (2 & 233, Figure 9, Appendix 1) occur within the area of Stornoway Harbour hence the map is to some extent speculative in its

GeoloGIS Report 2013/01	Geological information for Stornoway Harbour	Commercial in Confidence
Issue 1	Page 13 of 18	Date: 09/04/2013

detail. Nevertheless it suggests a general pattern of sediment becoming finer grained offshore, passing from gravelly muddy sand in the mid-harbour to slightly gravelly muddy sand then slightly gravelly sandy mud in the outer part of the harbour.

In the inner harbour, river sediment inputs are likely to have formed silty sand and/or gravel fans.



C12/11-CSL British Geological Survey. ©NERC. All rights reserved

Figure 9: Offshore seabed sediment map based on grain size analysis of the seabed samples from the localities shown by open circles; (copies of the records for samples 2 & 233 within the Harbour area are included in Appendix 1). Note that the classification may differ from that used in the BS5930 standard for geotechnical description

Reproduced from British Geological Survey 1:250,000 scale Sheet 58N 08W (Lewis), Sea Bed Sediments, by permission of the British Geological Survey. ©NERC. All rights reserved

GeoloGIS Report 2013/01	Geological information for Stornoway Harbour	Commercial in Confidence
Issue 1	Page 14 of 18	Date: 09/04/2013

#### 4 SUMMARY AND RECOMMENDATIONS

Geological and geotechnical information for Stornoway Harbour and adjoining areas have been obtained from a range of sources, including onshore and offshore maps only available at very small scale (1:100k & 1:250k respectively) and therefore very generalised. No mapping or modern description of the Quaternary deposits in the onshore or near shore area is available.

The succession in the harbour area is summarised as follows;

Deposit	Composition			
Onshore Quaternary and recent deposits	A discontinuous but complex mixture of till, sand and gravel, peat and wind blown sand with submerged peat, clay and beach deposits in the near shore area			
Offshore Quaternary and recent deposits	Sea bed sediments passing from gravelly sand to slightly gravelly sandy mud; probably resting on rockhead or glacial deposits in the inner harbour but with a silty mud wedge (Annie sequence) rapidly thickening offshore to 20 m or more in the outer harbour, overlying a variable thickness of till.			
Variabl	y irregular rockhead surface			
Tertiary intrusive dyke rocks	Basalt/dolerite in NW-trending dykes			
Jurassic rocks (thin sandstone and li persist into the outermost part of the h	mestone overlain by mudstone) occur offshore and may arbour although it is thought unlikely			
Permo-Triassic rocks: Stornoway Formation	Reddish brown conglomerate with subordinate sandstone and sparse lenses or beds of siltstone and mudstone with cornstone; dipping 10-45°			
Unco	onformity or fault contact			
Proterozoic or Archaean age 'Lewisian' metamorphic rocks of	Banded gneiss with pods of basic gneiss, variably deformed by a cataclastic fabric, with basic or granitic intrusions.			

The Stornoway Formation rests unconformably on the Lewisian gneiss beneath Stonoway and much of the harbour area, but in the west of the harbour the two groups of rocks are juxtaposed by a fault (or zone of faults); evidence of fracturing suggests that additional faults occur in the harbour area within outcrop of the Stornoway Formation.

The literature review undertaken for this work has been necessarily limited; a more detailed study of published and unpublished information may add significantly to the information presented.

It is recommended that a survey of the coastal exposures is completed in conjunction with the marine surveys. This will provide detailed data to support the interpretation of the marine surveys and will add considerably to information regarding the character of the deposits / rocks and structural features in the area.

GeoloGIS Report 2013/01	Geological information for Stornoway Harbour	Commercial in Confidence
Issue 1	Page 15 of 18	Date: 09/04/2013

#### 5 REFERENCES

BGS 1989a. Lewis. Sheet 58N 08W. British Geological Survey 1:250,000 Series: Quaternary Geology. BGS, Keyworth, Nottingham

BGS 1989b. Lewis. Sheet 58N 08W. British Geological Survey 1:250,000 Series: Sea Bed Sediments. BGS, Keyworth, Nottingham

BGS 1990. Lewis. Sheet 58N 08W. British Geological Survey 1:250,000 Series: Solid Geology. BGS, Keyworth, Nottingham

Fettes, D, J., Mendum, J. R., Smith, D. J. and Watson, J. V. 1992. Geology of the Outer Hebrides. Memoir of the British Geological Survey, Sheets (solid edition) Lewis and Harris, Uist and Barra (Scotland)

Fyfe, J. A, Long, D. and Evans, D. 1993. The geology of the Malin-Hebrides sea area. British Geological Survey UK Offshore Regional Report (London, HMSO)

Institute of Geological Sciences. 1981. Geological Survey of Great Britain (Scotland): Lewis and Harris (north), 1:100,000 scale.

Steel, R. J. & Wilson, A. C. 1975. Sedimentation and tectonism (?Permo-Triassic) on the margin of the North Minch Basin, Lewis. Journal of the Geological Society, London. Vol 131, 183-202

Stevens, A. 1914. Notes on the geology of the Stornoway district of Lewis. Transactions of the Geological Society of Glasgow. Vol 15, 51-63.

#### APPENDIX 1 OFFSHORE BOREHOLE LOG AND SEA BED SAMPLES

Log of borehole 78/4 and details of seabed grab samples attached

GeoloGIS Report 2013/01	Geological information for Stornoway Harbour	Commercial in Confidence
Issue 1	Page 16 of 18	Date: 09/04/2013

## INSTITUTE OF GEOLOGICAL SCIENCES

Continental Shelf Unit South

# COMPOSITE LOG Borehole No 78/4

Location: 9km. SE OF STORNOWAY

Actual position: Latitude: 58°8.6' N

Longitude: 6° 17.6' w

Dates of drilling: 12-13 MAY, 1978.

Total depth: 70.05 m.

Water depth: c.80m.

Navigation:

Positioning:

Contractor:

Vessel: M/s FERDER

Sea Area: MINCHES

Planned IGS No. 97

Licence Block: Querator

1.10000 Sheet No: 58"N 07"W

Georgists: J. A. Chenker D. L. Chenker C. C. Dengon M. C. Smith K. Rocker S. Brown

M Dean R Howes

IGS Barehole Nu 78/4

Ритрове	
Comments	

LITHOLOGICAL KEY			
CLAY/SHALF, MUDSTONE	A A A A A A A A A A A A A A A	EVAPORITES	
SILT/SILTSTOME	0 00 0 0 0 0 0 0 0 0 0 0 0 0	EXTRUSIVE IGNERUS	
SANO/SANOSTONE		INTRUSIVE IGNEOUS	
SRAVEL/CON SLOMERATE		BASEMENT	
LIMESTONE	1/22	WHOLE SHELLS/SHELL FRAGMENTS	
CIIALK	C P	CARBONACIOUS PLANT FRAGMENTS	
DOLOMITE	☐ H	IRON PYRITES / FERRUS INDUS	potar on P
COAL/UGNITE	-	CALCARBOUS	
		- to the second	

AGE	0								100		LOGY	DESCRIPTION	SUB SAMPLES	COMMENTS
1		Log		45T	Ru	N						38. 3	1	
	+	Ť	Γ		1	1	7	(m be	epth Now evel			Carl May .		
T	5	cate:	1: 2	100	,	$\top$	1		Т		17			
	- 1	+	+	$\vdash$	-	+	+	+-	1		X			CONTRACTOR OF COLUMN TWO COLUMNS AND ADDRESS AND ADDRE
- 1	1	-	-		-		+	+	╀	7.47.47 4.49.97		CLAY: CHEC STEY (MONTH STY)), 2-177, SOFT TO VERY SOFT.	C 888.7	**************************************
	L	١.	L			_			L			190	No h Sale of Francisco	1 4 2 3 22 E M
- 1											1			
1	- 1	$\top$				+	+	+	+			star : (65 ABANE)	CO Day	المستعملات مسلامية
	-	+	-	Н	-	+	+		-	-			-1.6a-/	14 7m Hills Com of Miller
		1				_	1	_	L			\$ 1000 Feb. 9 200 2 1 000 0005. 4 5000	e-n.ea.	Assert Ay and a
												CLRY: DARK SALT.  STORMAN STATE DEPORTED STATE SETT OF VERY SET	FY. MILL	- Water State
		+	ļ			1	+				10	STORING FILE DEWNERRYS.	them.	
	1	+	1	H		÷	+	+	+			enge " person e	bus our at	THE RESERVE AND ADDRESS OF THE PARTY OF THE
		_	1			1	1	ļ.	1	-			L. C.	+ Adoletonal definited
							1	1				CLAY : YERY DARK GREY, MINING (MARKELLES ME R.). SHITT ENS. JAMES MAYER	€ 9.1 <sub>€</sub> ,2	+ Additional definited  Hi Pad son plang  20-2-85
- 1						$\neg$	1		-				FRALL "	20-2-85
	- 1	-	H	1	-	+	Ť	+	i		X			
	1	_	ļ			4	+	4.	1	-	É	(LEV: (St. Store) Recolling morres my San	H. FALL	
- 1	Í							1	25.	700		CLAY: (HS REDVE), BECOMING MODERATELY FIRM DECOMPLES SUBMIT SHELDY BENDING GEVELOPED.	E. S. Park	er 212
	- [								1	7			←M, Peca	
	1	-	t			+	+	-	t			a company and a second account	enths of	W
- 1	+	+	╀	$\vdash$		+	+	.j.,	e	-		CLAN (F.S. DESONE), W. CLOSENE SCHOLLERS	Entract on	10
	- 1								1.		J		€n.Pat/	ery
7													En face	rid.
×	- 1		1			$\top$	$\top$	$\top$	1	-		CLMY : 'As Astre)	En Pac	A STATE OF THE PARTY OF THE PAR
<b>Œ</b>		+	į.			+	+	+	+		202		E17807	The state of the s
7	L	$\perp$	L						1		1	VOCASIONAL SERVICIO DOS CONCORDANAS DESCRIPCIONAS COMPANSAS ARRAMANAS DE CONCORDANAS DE CONCORDADAS DE CONCORDANAS DE CONCORDADAS DE CONCORDA	+ h .59.7	erve:
8	.	1	ŀ											
ш	Ī	1	T				1				1			
-	- 1	+	+	$\vdash$		4	+	+	+		7.5	CLAY: (AS ABOVE), GOFT-TO FIRM DOWNWARDS	(-r. fac./	Contract of the contract of th
I	-		-	-		1	+		-	E.	X			
3		1	1								(A.)		ERMOZ COS	Dollar a management
0						1						CLAY: DARK GREY, SKTV, FINE TO PROCESTELY STIN COMMINKAL FEBRUES.	E FAU.	er (*
	ŀ	+	+	-		7	-	+	1		1-2-	* 63	em day	
	}	+	+	1	-	-		- 3	50.		Y	para cana and a		except add to the transfer of
- 1			L				- 3	1			:(_)	C.AY (7: Atove)	ente	page community to the community of the c
										. 3 .	00.00	THE THE STATE STATES OF THE STATES AND COMMENT OF THE STATES OF THE STAT	:	
		-	1				1	T	T	2	X	CLAY : REE BROWN, SHTY, NET RE-SHRTER "GASSROT" CLAS. E	4	and the second s
_	-	m	4	~	M	~	~~	~~	~~			CLAY (TO MODE)  CLAY (TO MODE)  CLAY (TO BOUNDESSY) (ACTION TO THE ACTION OF CARD TO THE ACTION TO T	← 17. file.	(SS TYM)
		4	-			1	-	1	-			PARELY SHELLY	E-H.Pas.	
	1	-			П			-	T		X			and the second second
	1	+	+	-	H	+	+	-	+				Z H 0-	ž.
			-		-	4	-		+			SHALE : (AS ABOVE)	←H-Pas.	C-0446 OF 5554. June 15:00
										-		SHALE MASSONS HACK SOFT LELERTONS FOREY FEISTER	6-11. Fee.	
			T		П	П						Poorty Fisher	E-M.Pat.	The second second second second
	ł	-	1	1	H	+	+	-	-		-	PROBLE ! FISCHE  SPAIL   HUBSTONE ! BLENK, SOFT, NACHABAUN  ABACERT (RICHEROUS SUBLI FRAGMENTS  FRANCHIT SHAN TESTAT		1,140
		-	+	ļ	Н	$\vdash$	+	0 7	olo:	-	4.5	REMARKS SHELL PRISERT	E-M.Phi.	Commence of the Contract of th

2 58-**47** Continental Shelf Unit II. Institute of Geological Sciences.
Sample Data Sheet DAA PB Wet greateth day. 1.35 M 36.28 - 2 S 7.64 43.92

Radar	Sextant 3	iting	Descring	(T)	Hanos (N.M.)
Decca		60	MP	NORM	SCOTTISH
Daooa	Position	Rod GI	·72Mireen		MINDLOF 69.55

Vessel	HARIA W	
Depth (E)	43	17 62 67 7.1
Time	0735	
Date	3 Q ALIG 1969	
Sample Mod	b 3c/84	
Semile No.		

5

# SAMPLE DESCRIPTION SHEET BRITISH GEOLOGICAL SURVEY — MARINE GEOLOGY UNIT

SAMPLE NO. +58 -φ7 233

SURFACE SAMPLE Equipment Used: 65 Seabed Photo: Yes/No Stored in: 1 Jans, Bags.

WS v. fine wordy sand, v. set whead.

	-						
CORE	SAMPL	Equipment Used: CS	Stored in:	Cut Cores, 2			Bags.
Depth	Log	Description	Core Photo:	Yes/No	Sub Samples	Geotechnical L	.og
(m)		2 Cover laken for weather out or spl	it.				
1		buc'u v. soft only					
2 —		544/1 de frags.	wh grey	. Exc'l shall			
3		Sample Kept from a	hocker K	acio.			
	9						
4-							
5 —							
6 -						o shear Δ cor	

SAMPLE STATION DATA  BRITISH GEOLOGICAL SURVEY - MARINE GEOLOGY UNIT  SAMPLE NO.  SAMPLE NO.  Lot 2 long no.	2,33							
CRUISE NO.  DATE  TIME (local)  WATER DEPTH POSITION FIXING METHOD  COMMETHOD  CHAIN  RED  GREEN  PURPLE  NAVIGATIONAL READINGS (tick lanes with best intersection)  RED  OATE  TIME (local)  WATER DEPTH POSITION FIXING METHOD  PURPLE	32							
POSITION  LATITUDE  LATITUDE  LATITUDE  LATITUDE  LATITUDE  LATITUDE  LONGITUDE  LONGITU								
ADDITIONAL INFORMATION:								
EQUIPMENT TYPE: 1 = sample recovered 3 = no sample (equipment failure) 2 = no sample (geological reasons) 4 = no sample (undifferentiated)								
G dup cols 2-11 ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) (								
SUMMARY SAMPLE DESCRIPTION : (Free text - max 69 characters)	<u> 1</u>							
H 2015 V. F. N.E. MUDDY, S. AND, D. V.E.R., V.ERY, S. B. F.T.  BARELY, SILLTY, CLAY, WITTH, OC. 5' L. 3. H. E. L. L.S.								
GEOTECHNICAL DATA:  RAW DATA  PENETROMETER  HAND VANE  Head  Readings  Head  Readings  Head  Readings  GEOTECHNICAL DATA:  AVERAGED DATA  DEPTH  PENETROMETER H.  (KPa)  (KPa)  (KPa)								
I dup cols 1.4 1.1 18	22							
	55							
The dup is so	77							
T cols 25 14 18 19	22							