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Client SHETLAND ISLANDS COUNCIL
Title YELL SOUND TUNNEL PROJECT
Project No. MM0209

YELL SOUND TUNNEL PROJECT

**ENGINEERING GEOLOGICAL MAPPING
& MARINE STUDIES**

ON BEHALF OF

SHETLAND ISLANDS COUNCIL

JUNE 2002

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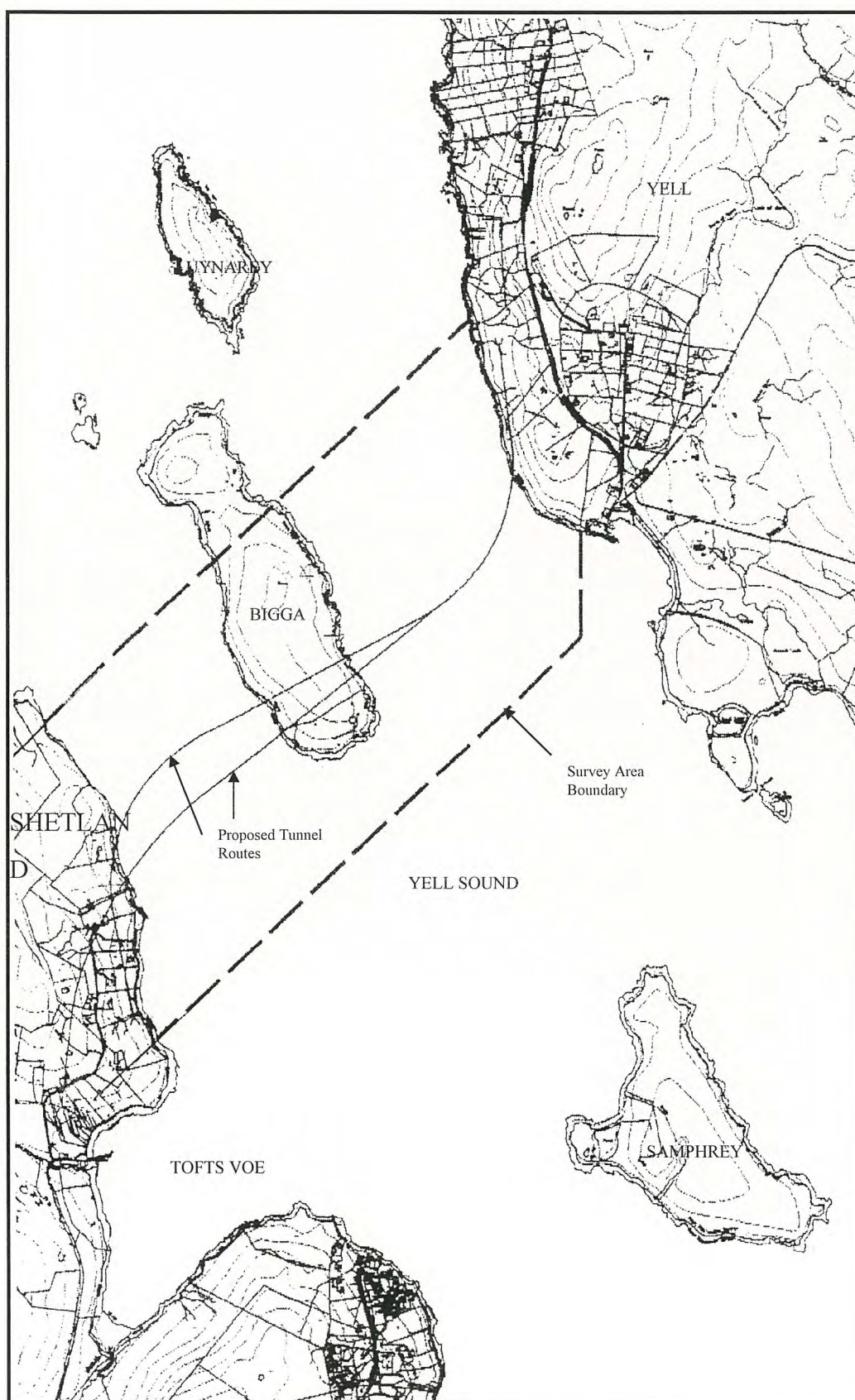


Figure 1 – Location Plan of Survey Area



1.0 INTRODUCTION

Caledonian Geotech Ltd were contracted by Shetland Islands Council to conduct a geophysical and hydrographic survey over a corridor route in Yell Sound running from Shetland Mainland across to the island of Bigga and from Bigga across to Yell. Shetland Islands Council is considering plans to construct a deep submarine tunnel connecting Shetland Mainland to Yell, via Bigga, as an alternative to the existing ferry link.

The scope of work included geological mapping, echo-sounding and seismic surveys, using a 'boomer' system. In addition a few lines were acquired using a 'pinger' sub bottom profiler in order to achieve high resolution of the superficial sediments.

The actual survey area which is shown in Figure 1, Location Plan of Survey Area, comprised two sections each approximately 1000 x 1500m on either side of Bigga Island. Survey lines were run on a southwest-northeast orientation at 50m line spacing parallel to the route axis and on a northwest-southeast orientation at 100m spacing perpendicular to the route axis. In total about 150 line kilometres of seismic and bathymetric data were acquired over the course of the survey from May 12th – May 18th 2002.

The survey objectives of the site investigation were:

- to determine the seabed levels and locate any irregular relief;
- to determine, if possible, the sequence of strata, extent and depth of subsoils and the nature of the soils and sediment layers comprising the overburden;
- to establish bedrock profile and levels;
- to conduct geological mapping of the foreshores on Shetland Mainland, Bigga and Yell;
- to correlate the geological survey information to the marine survey, to assist in the identification of fault zones and structural trends;
- on the basis of the survey results to advise on any future survey or investigative procedures which might benefit the Client in gaining a fuller understanding of the site area.

This report provides details of the methods and equipment used together with the survey results, conclusions and recommendations drawn.



R.S. DISCOVERY ROSE



R.S. Discovery Rose, towing the boomer catamaran, in Western Yell Sound, between the Shetland Mainland and the Island of Bigga.



2.0 EQUIPMENT AND METHODS

2.1 SURVEY VESSEL

The acoustic survey was conducted from Caledonian Geotech Ltd's hydrographic survey vessel, R.S. Discovery Rose. The vessel, which is 19.75m long and weighs 43.91 tonnes, has been specifically refitted for survey purposes. A 'moonpool', fitted forward of the accommodation, allows the deployment of acoustic sensors (echo-sounder and 'pinger' sub-bottom profiler). Directly above the 'moonpool', a navigation mast carries the GPS antennae: the co-axial alignment of acoustic sensors and the navigation antenna eliminates the need for the application of offset corrections to the echo-sounder and 'pinger' sub-bottom profiler positional data.

A 250kg derrick and winch, fitted at the stern of the vessel, was used to deploy the boomer system on the starboard side of the vessel. The survey configuration of the geophysical equipment is illustrated in Appendix 4.0, Sensor offsets.

2.2 NAVIGATION

Vessel navigation was provided by a Navsymm XR6 Real Time Kinematic Global Positioning System (RTK DGPS) comprising two, 12-channel receivers. The base station receiver was positioned over a survey station, Firths Hill (Refer Appendix 1.0, Survey Station Descriptions). Pseudo-range and carrier phase corrections were transmitted via a Microtel VHF radio telemetry link, to the mobile GPS receiver onboard the survey vessel, at 2 second intervals. The mobile GPS receiver then transferred the differentially corrected vessel position to the navigation computer.

The vessel's position was logged at one second intervals, to computer hard disk, in real time, using the EIVA 'Navipac' online navigation software. Every 10 seconds, a position 'fix' was generated, at which time a hard copy of the vessel's position was printed and a fiducial mark transmitted to the graphic recorders.

A helmsman's computer and monitor were linked to the navigation computer in order to display survey lines to provide guidance for the helmsman during the survey. As 'real time' positions were fed to the computer by the navigation system, so a visual record of the coverage of the survey area was compiled.



2.3 ECHO-SOUNDER

Bathymetric information was acquired by means of an Odom Hydrotrac echo-sounder with a 200kHz transducer mounted below the moonpool on R.S. Discovery Rose. Corrections for draught and speed of sound in sea water were determined by the standard bar check method. No layback corrections for echo-sounder data were necessary since the transducer and navigation antenna were coincident in the vertical axis. Echo-sounder records are continuous; spot depths on the bathymetry chart are provided at set spacings for clarity.

The echo-sounder was operated continuously throughout the 'pinger' sub-bottom profiler and 'boomer' surveys. Data was reduced using tidal information obtained from shore based tidal dippings at Station Toft 2 DP and the tidal curve so derived is provided in Appendix 2.0, Tide Curves.

2.4 SUB-BOTTOM PROFILERS

The main survey technique employed a GeoAcoustics boomer system to acquire high resolution information of the overburden above rockhead level. On site trials were run to test the effectiveness of an analogue sparker and a boomer system. This concluded that the boomer system gave superior data overall and this system was then employed for the subsequent survey. The boomer was operated at 200 Joules, which provided sufficient penetration to delineate the top of rockhead and sufficiently resolute detail to reveal bedding of the overlying sediments.

The boomer catamaran, from which the seismic energy is output, was towed at an average distance of 25m astern of the starboard side of the vessel. A hydrophone array, trailing parallel to the boomer on the port side, received the reflected energy from the seabed and sub-seabed reflectors building up a 'picture' of the geology below the seabed as the vessel progressed through the water. Data is output to an EPC thermal recorder - after signal amplification and filtering - and annotated with positional information. A continuous analogue print out is acquired on a vertical 'time' scale, which displays the sub-seabed geology as a series of 'reflectors'. The interpretation technique involves selecting significant reflector levels, which mark changes in lithology, and converting the time based records to unit thickness or depths below seabed. Data was output on the EPC recorder at a sweep speed of 66msec, which equates to a theoretical seismic penetration of more than 60m



below seabed. Rockhead level at this site is close to seabed or outcropping so the seismic energy is rapidly attenuated on entering the rock fabric; the effective seismic penetration is consequently less than the theoretical value.

A few test seismic lines were acquired using a high frequency (3kHz-7kHz) ORE 'Pinger' sub-bottom profiler system in order to provide high resolution information of the seabed sediments. It was concluded that the slight gain in pinger resolution in the upper layers was of no overall benefit as the pinger system failed to achieve sufficient penetration to clearly illustrate the top level of rockhead. As a result the boomer system was maintained as the primary seismic acquisition tool.

Data quality was generally good although some lines were degraded by noise, generated either by marginal weather conditions or standing waves, which formed in response to strong tidal streams. Strong currents can also lead to a compression of data when the vessel heads into a strong current - or the reverse - a stretching of the data when strong currents cause too fast a traverse. Several seismic lines were duplicated to resolve these problems.

During post-processing an assumed seismic interval velocity of 1675 m/s has been used to convert travel times to depths.

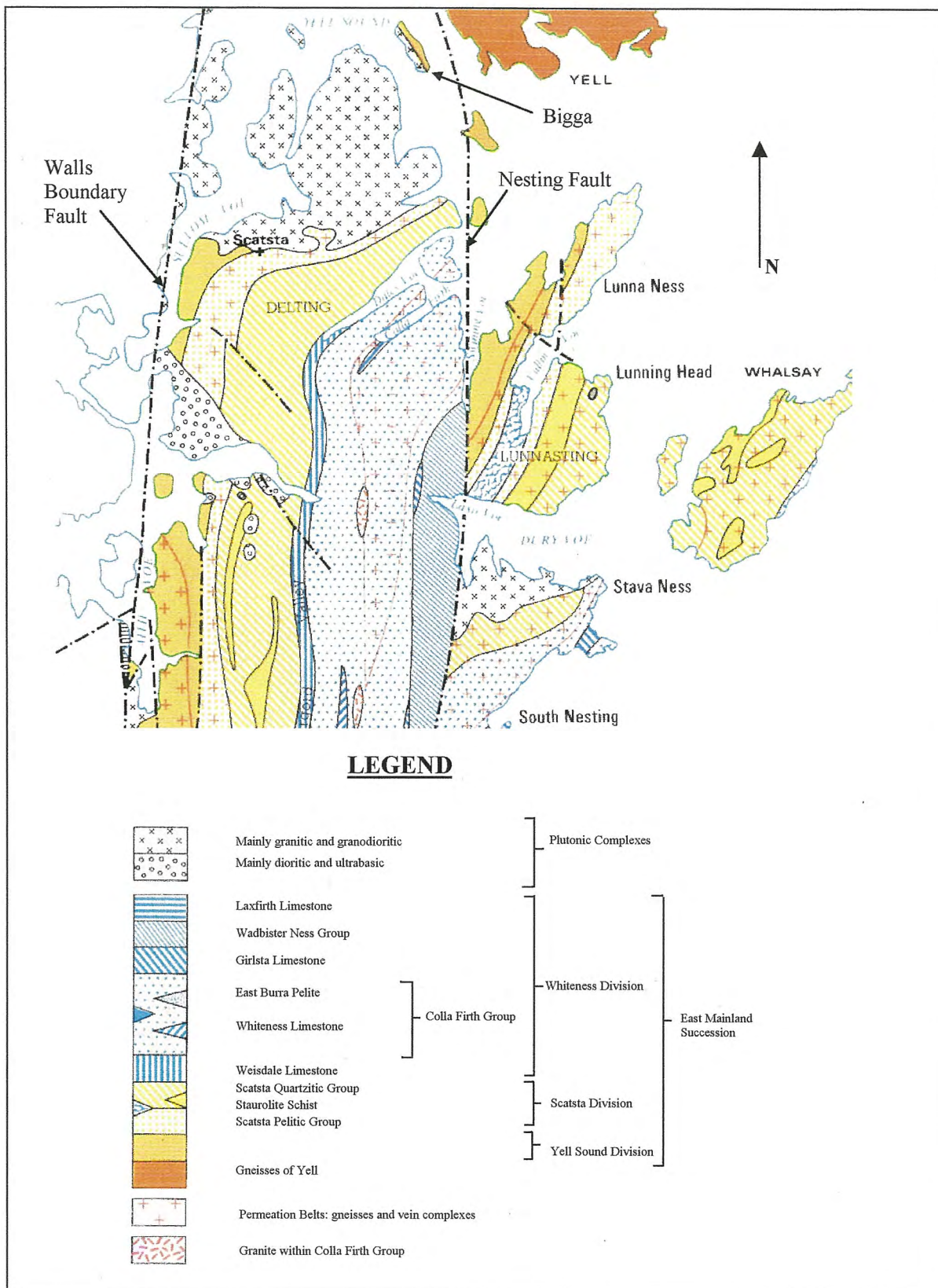


Figure 2: Extract from Geological Map of Shetland East Mainland (Mykura 1976, p.30)

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3.0 THE GEOLOGICAL SETTING OF YELL SOUND

3.1 GEOLOGICAL BACKGROUND

Yell Sound is a 3Km wide, glacially excavated NNW-SSE trending sea passage-way separating the Shetland Island Mainland and the largest of the northern Shetland Islands, Yell.

A plethora of small islands and skerries are arraigned along the axis of the sound, which results in a topography which undergoes considerable – and sudden – changes, over distances of less than half a kilometre.

Within the area of the proposed tunnel crossings, the sound is split into two deeply excavated valleys separated by the elongate island of Bigga, whose axis parallels that of the sound, and local topographic changes, of the order of 80m or more, are to be found between the high point of the island and the depths of the two main channels to either side.

Strong geological controls are responsible for the creation of the sound, and their origins and local influences are briefly summarised here.

Reference should be made to the extract from the geological map for the area (Fig.2). It will be seen that two principal suites of rock occupy the area, and that these are, furthermore, separated into eastern and western provinces along the central axis of the sound. To the east – the eastern half of Bigga, and the West Yell foreshore – the ground is occupied by a succession of sedimentary rocks that were subjected to regional metamorphism during the mountain building episode known as the Caledonian Orogeny, which came to its conclusion approximately 400 million years ago. During the latter stages of that period, granitic magmas were intruded into the metamorphosed sedimentary pile; these rocks now occupy the western half of the island of Bigga, and the Shetland Mainland along the shorelines of the western sound.

During the regional metamorphism, the rocks were subjected to strong compressions and some heating, as the mountain ranges were created; this resulted in changes in the types – and, more importantly, perhaps, in the orientations - of the minerals within the rocks. The effects of these ancient stress fields can be seen today as a sheet-like banding within the exposed rocks – a foliation – which has, in addition, been folded in places. The alterations in strength, furthermore – which are associated with the foliation - have resulted in the formation of sharp-edged ridges of



harder or stronger rock, separated by narrow gullies, occupied by softer or weaker sequences. Whilst the influences of these compressions can be seen clearly in the metasediments occupying the eastern section of the survey area, in the granitic rocks of the western sector the imprint is less pronounced – the granitic material having been intruded into a reducing stress field during the latter part of the orogeny.

Following the major events of the Caledonian Orogeny, the rocks were subjected to two principal episodes of faulting. The first of these is associated with transcurrent, dextral displacements along fundamental crustal fault structures (of which the Walls Boundary Fault and the Nesting Fault – which pass along the eastern sound – are examples) – whilst the second involved numerous, though less fundamental, structures which cross-cut (and sometimes displace), the earlier, major faults.

The combination of foliation and faulting has resulted in the local geology having very variable – and suddenly changing – rock strengths. These have been exploited during glacial times, when migrating glaciers preferentially excavated the zones of rock which had been weakened by faulting. Subsequent erosion by marine processes has resulted in further preferential erosion which can be seen on a small scale in the photographs in the form of localised gullies which surround zones of faulted material



Photograph 3: Foliated schists adjacent to shatter/shear belt, Bigga east coast, geological locality
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3.2 LOCALISED GEOLOGICAL MAPPING

3.2.1 THE EASTERN PROVINCE (The eastern half of Bigga and the western shoreline of Yell)

3.2.1.1 Lithology

The province comprises regionally metamorphosed sedimentary sequences. The rocks on the East coast of Bigga form part of the Yell Sound Division of the East Mainland Succession. They were mapped by the British Geological Survey (1968) as 'semipelitic schists' and 'semipelitic schists permeated by granitic material'. This has been verified in the survey area, where they consist of strongly foliated schists which have a steep foliation trending across the channel separating Bigga from Yell (an exception to this pattern was seen on the south-eastern coastline of Bigga where the foliation is disturbed by abundant shearing). Photo 3 shows how these rocks typically appear in field exposures in the survey area.

The rocks on the West coast of Yell are tentatively correlated to the Yell Sound Division of Shetland Mainland, and consist predominantly of muscovite-biotite gneiss and 'silvery mica schists' with many veins of pegmatite. In the survey area they occur as pelitic mica schists with a strong foliation trending sub-parallel to the channel separating Bigga from Yell (see Photo 4). They contain abundant pegmatite veins, sheets, and lenses, which have been boudinaged in places and cause local distortions to foliation orientations (see Photos 4, 5 and 6).

3.2.1.2 Structure

Rocks in the survey area form part of the sedimentary succession of Shetland which was metamorphosed during the later stages of the Caledonian Orogeny (*circa* 400 million years ago) with contemporaneous intrusion of plutonic complexes. Flinn (1967) concluded that only one period of intense deformation, associated with the Caledonian Orogeny, is recognisable in the East Mainland Succession.

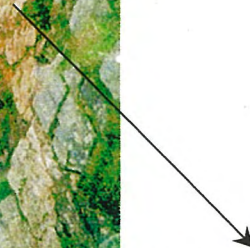
The rocks in the survey area on the east coast of Bigga have been identified as being part of the East Mainland Succession and those on the west coast of Yell are tentatively correlated to it. It is thus quite likely that the deformation episode identified by Flinn (1967) in the East Mainland Succession was also responsible for the formation of the prominent foliation present in the rocks



Orientation of principle foliation



Orientation of
pegmatitic vein



Photograph 4: Pelitic schists displaying prominent foliation with cross- cutting pink pegmatite vein, Yell west coast, geological locality 2



along the coastlines of Yell and East Bigga. Structures present within the survey area are separated for ease of discussion into those attributable to the main phase of deformation discussed under Section 3.2.1.2.1 (most notably foliation), and those attributable to post-main phase deformation (brittle faulting).

3.2.1.2.1 Main Phase of Deformation (formation of foliation)

Photographs 1, 3, 4 and 5 exemplify the well-ordered, foliated fabric, which was imprinted upon the sequence of sediments during the episode of deformation. In addition to this very profound and easily recognisable principle foliation, there are minor folds, of both long and short wavelengths, which have been attributed by others to the same, single, principal phase of deformation (Flinn, 1967, Mykura, 1976).

The orientation of the principal foliation varies considerably across the survey area: The foliation in rocks along the east coast of Bigga strikes across the channel separating Bigga from Yell. Stereographic projections of foliation orientations measured in this area give an average strike orientation of 079° (steeply inclined) south of geological locality 10 and of 020° (dipping on average at 48° towards 110°) to the north of this position. (Strike direction is the azimuth of a horizontal line drawn along the surface of the plane of dip in strata – ie it is a stratum contour). The change in foliation orientation is likely to be a result of the faulting identified at locality 10. In the region of geological localities 12 to 15 near to the southern tip of the island, foliation orientations are very variable as a result of disruption by the many faults mapped in the area (see Drawings MM0209/W4 and MM0209/E4, Contoured Surface of Top of Rockhead).

The West Coast of Yell

Although variable, foliation orientations on the west coast of Yell strike sub-parallel to the channel separating Bigga from Yell (see Photo 4). Stereographic projections of foliation orientations along this coastline give an average strike of 155° (ie foliation dipping at 68° towards 065). It is thus apparent that there is a considerable change (i.e. 76°) in foliation orientation across the eastern



Folding of foliation, locally
around boudin



Extensional Axis

Photograph 5: Isoclinal folding in pelitic mica schist with small pegmatitic boudin, Yell west coast, 250m East of geological locality 6



Photograph 6: Exposed pegmatitic boudin with pelitic schists preferentially eroded around it, Yell west coast, 445777,1179937 (GPS co-ordinates)



sound. The most likely explanation for this change in strike is rotation or displacement across the Nesting Fault system, which separates the two areas from each other.

Rocks mapped on the west coast of Yell are intruded by many pegmatites, some of which are boudinaged within the planes of the foliation (boudins – from the French word for ‘sausage’ - are present in the form of pods within the rock structure). Foliation can be seen to be folded around boudins in places (see Photo 5 & 6). The orientation of these boudinage structures indicates that they are attributable to the same phase of deformation which resulted in the formation of foliation. Owing to the pegmatites being harder and more resistant to erosion than the schists which host them, some boudins along the coastline can be seen to stand almost completely free of the softer schists, which have been preferentially eroded (see Photo 6).

3.2.1.2.2 Post Main Phase Deformation

Faulting occurred in two principal phases: the first of these resulted in faults arranged parallel to the channels, whilst the second resulted in faults which cross-cut them.

Structures sub-parallel to channels

A major fault system was identified during this survey - close and sub-parallel to - the channel axis between Bigga and Yell (see Drawings MM0209/W4 and MM0209/E4, Contoured Surface of Top of Rockhead). Although its orientation varies, this fault system strikes, on average, at 170° through most of the survey area. It corresponds in both orientation and position to the transcurrent Nesting Fault, which is believed to have a dextral displacement of some 16km (Mykura, 1976).

Within the survey area, the Nesting Fault system is interpreted as a zone of major weakness. It is most probably responsible for the very formation of the channel between Bigga and Yell, which has been excavated to a greater depth than the flanking terrain as a consequence of preferential erosion by ice during the last glaciation. The depth and steep sides of this channel stand testament to the relative ease of erosion of the broken ground associated with this feature. This specifically-sited erosion, in turn, implies that there is, indeed, an inherent weakness within the rocks, which may well persist to considerable depth.



Photograph 7: Shatter/shear belt on Shetland Mainland coast at geological location 24. Note the blocks of host rock contained in the shatter/shear belt.



Photograph 8: Photograph of shatter/shear belt on Shetland Mainland coast eroded into gully at geological location 25.





Towards the southern end of the west Yell shoreline, two steeply inclined faults were mapped – having similar orientations and striking, on average, at 142° . In this area, the Nesting Fault trends at approximately 155° . The sub-parallel orientations of these two, smaller faults to the Nesting Fault implies that they may well be secondary structures related to it.

Structures cutting across Channels

A number of steeply inclined shatter/shear belts were identified striking across Yell Sound. They range in width from 6m to less than 0.5m, and consist of brecciated, angular rock material ranging in size from blocks greater than 40cm in diameter to particles having a fine grain size (*see Photo 7*). The recognisable brecciated rock material they contain comprises almost completely host rock material, indicating that they are caused by relative movement, shattering and granulation of the rocks within which they are sited. Foliation orientations can be seen to change across these structures in places, implying that there has been considerable displacement or rotation across them. Some of these shatter/shear belts in the channel separating Bigga from Yell are sufficiently well developed to enable them to be identified by geophysical techniques, allowing along-strike extension into Yell Sound.



Photograph 1: Foliated granitic gneiss adjacent to shatter/shear belt, geological locality 26



Photograph 2: More massive granitic gneiss, Bigga west coast, 50m NW of geological locality 18



3.2.2 THE WESTERN PROVINCE (The western half of Bigga and the eastern shoreline of the Shetland Mainland)

3.2.2.1 Lithology

The province comprises intrusive granitic rocks. The rocks in this area form part of the late-orogenic Graven Complex which consists of two main phases of intrusion of mostly granitic material into regionally metamorphosed country rocks (Mykura, 1976). In the survey area, these rocks generally occur as either foliated, banded granitic gneiss, with a steeply inclined foliation which trends across the channel between Bigga and the Shetland Mainland (Photo 1), or as more massive granitic material (Photo 2).

3.2.2.2 Structure

Mapping of the Graven Complex rock outcrops exposed on the Shetland Mainland and west Bigga coasts revealed a similar foliation and banding in the rocks to that seen elsewhere. The Graven Complex was emplaced before the cessation of Caledonian Orogenic activity, which was responsible for the foliation developed within it. Examination of large scale geological maps of the area reveals that the Graven Complex lies within the same palaeo-tectonic regime as the East Mainland Succession. It is therefore likely that the episode of deformation identifiable in the East Mainland Succession was responsible for the development of foliation (where it is present), within the Graven complex in the survey area.

After the main phase of deformation, the East Mainland Succession and the Graven Complex were disrupted by a number of approximately N-S trending faults, including the Nesting Fault and Walls Boundary Fault. Geological maps produced by Mykura (1976) show that the Nesting fault system trends NNW-SSE locally within the survey area.

3.2.2.2.1 Main Phase of Deformation ((formation of foliation)

Measurements taken during the current geological mapping exercise show that foliation along the Shetland Mainland coast strikes across the channel which separates the Shetland Mainland from Bigga. Stereographic projections of representative foliation orientations measured along the



Shetland Mainland coast, south of geological locality 21, give an average of 041° . To the north of locality 21, foliation orientation was measured as striking 007° . One possible reason for this change in strike is rotation across the fault mapped at geological locality 22. Northwards of this point, the rocks become massive (unfoliated), as far as geological locality 21; thereafter, foliation is identifiable, striking in a more north-south direction. Alternatively, this change in strike may be attributable to local variations in the regional stress field that existed during the main phase of deformation or to a later episode of folding.

The rocks along the west coast of Bigga also strike across the channel separating the two coastlines. Owing to time constraints and limited accessibility, only sparse measurement of foliation orientation, providing a strike direction of 063° (Figure 3) was possible along the west coast of Bigga. More measurements than time permitted would ideally be required to confirm the consistency of this orientation.

3.2.2.2.2. Post Main Phase Deformation

The present geophysical survey indicates that despite having a similar orientation to that of the eastern sound between Bigga and Yell, the formation of the channel separating Bigga from Shetland Mainland cannot be attributed to a similar mechanism. Whereas in the eastern sound a single, major structure in the form of the Nesting Fault is almost certainly responsible for its creation, in the western sound the geophysical survey revealed a number of discontinuous faults of variable orientations (striking between 010° and 120°). It appears that these discontinuous faults have collectively weakened the rocks along the axis of the channel separating Bigga from Shetland Mainland.

The steep sides and depth of this channel show that the faults have formed a wide, weakened zone which has been susceptible to preferential weathering and erosion – once more, most probably, by glacial action – which has resulted in the formation of the present day channel. The mechanisms of formation of the two channels do appear to be somewhat different; whilst both result in a glacially deepened channel, the less regular nature of the seabed along the channel axis between Bigga and Shetland Mainland - when compared with the seabed along the Nesting Fault - is testament to the more diffuse zone of weakness caused by multiple faults in the western sound.



Structures cutting across Channels

All shatter/shear belt orientations were plotted onto separate stereonet for each mapped coastline for comparison and interpretation. Comparisons of these plots show that the shatter/shear belts on Shetland Mainland and both the east and west coasts of Bigga have very similar orientations: they plot in two clusters on the stereonet giving average strikes of 034° and $072^{\circ} (\pm 14^{\circ})$. Their similar orientations suggest that the relative orientations of these features have not been affected between the three coastlines and that they may thus be considered as a single suite of shatter/shear belts.



3.3 DISCUSSION OF GEOLOGICAL SETTING

3.3.1 Lithology

It has already been seen that there are two very different suites of lithologies present, having a boundary running in a NNW-SSE direction along the central axis of Bigga; this separates the rock types which will be encountered in Yell Sound into an eastern and a western province. Both suites of rock were affected by the stress fields existing during the Caledonian Orogeny, which imparted to them a common foliation. The metasediments of the eastern province are more clearly foliated than the granitic rocks of the western province, owing partly to the lithological differences and partly to these latter being intruded at a later stage, when stress fields were reducing. The eastern sound is thus flanked – and underlain by – semipelitic schists, sometimes permeated by granitic material, in its western section, and muscovite-biotite gneiss and “silvery mica schists”, both of which contain veins of pegmatite – in the east. These rock types are separated by the Nesting Fault which runs along the eastern sound.

The western sound is flanked and underlain by the variably foliated granitic intrusions of the Graven Complex.

3.3.2 Structure

It has been stated under section 3.2.2.2. that measurements from the cross-cutting structures, exposed along the east Shetland Mainland coast and both coastlines of Bigga, plot as two, rather diffuse, clusters on stereo-net plots.

In order to obtain definitive geometries of the structures, a significantly more extensive mapping exercise than that currently undertaken would be necessary. It is the case, however, that diffuse clusters of brittle structures having average strike directions of 034° and 072° are present, and the poles to these structures fall into the same quadrant as the poles to the foliations, suggesting that the foliations present are, to some degree, affecting the orientations of the latter fractures. (The two clusters are formed roughly parallel to the foliation and at 40° to it).

On the western shore of Yell, furthermore, where the foliation is sub-parallel to the shoreline, the shatter belts are, once more, orientated parallel to the foliation and at angles of 40° or so to it – once more suggesting that foliation is affecting the mode of fracture.



Two explanations do exist for this geometry: first, the cross-channel fractures are being simply controlled by the foliation - in which case they can post-date the Nesting Fault; second, their similar relationships to the foliation locally could be a consequence of these fractures being formed prior to the transcurrent faulting associated with the Nesting Fault. In this case, the Yell Gneiss block, having been translated and rotated concurrent with the movements along the Nesting Fault contain the pre-existing regional fractures, having a similar geometry to the foliation. The final orientation of the fractures in this case would depend upon the degree of rotation of the Yell gneiss block.

The significance of the two possibilities is that in the first case the Nesting Fault may be offset by later, cross-channel structures, whereas in the second case, the Nesting Fault will offset pre-existing structures. The geophysical records suggest that the former is the case, but without extensive further mapping and, preferably, specifically flown air photography, the issue cannot be decided. The charts, consequently, do represent the former of these explanations as being the explanation, based on supporting evidence from geophysical records.

On shore, many of the cross-channel trending shatter/shear belts are eroded into deep gullies or embayments in the coastline (see Photos 1,2,3,7 & 8), indicating that they are zones more susceptible to weathering and erosion than their host rocks. Further, it can be seen that the now sub-sea bedrock has been preferentially eroded along some of these features, resulting in ordered irregularities being present in total cover isopachytes in places, demonstrating the presence of the troughs and ridges which are present below, at shallow depth. These shatter/shear belts are thus interpreted as being present throughout the survey area, imparting weakness and greater susceptibility to weathering and erosion than the surrounding rock. If they are present at depth, they will also be sites of potential water ingress through broken ground.

On the west coast of Yell, an additional set of faults and joints are exposed. These have a trend direction of 142°- sub parallel to the Nesting Fault, locally; it is concluded that these structures, absent elsewhere in the area, have been formed during the Nesting Faulting episode.



4.0 MARINE SURVEY RESULTS

The results of the hydrographic and seismic surveys are presented on the following charts, which are contained in Appendix 6.0 of this report:

Drawing Nos.	Drawing Title	Scales
MM0209/W1	<i>Shetland Mainland to Bigga</i>	
	Bathymetry	1: 2,500H
MM0209/E1	<i>Bigga to Yell</i>	
	Bathymetry	1: 2,500H
MM0209/W2	<i>Shetland Mainland to Bigga</i>	
	Isopachtye of Sand	1: 2,500H
MM0209/E2	<i>Bigga to Yell</i>	
	Isopachtye of Sand	1: 2,500H
MM0209/W3	<i>Shetland Mainland to Bigga</i>	
	Isopachyte of Overburden above Rockhead	1: 2,500H
MM0209/E3	<i>Bigga to Yell</i>	
	Isopachyte of Overburden above Rockhead	1: 2,500H
MM0209/W4	<i>Shetland Mainland to Bigga</i>	
	Contoured Surface of Top of Rockhead	1: 2,500H
MM0209/E4	<i>Bigga to Yell</i>	
	Contoured Surface of Top of Rockhead	1: 2,500H
MM0209/W5	<i>Shetland Mainland to Bigga</i>	
	Interpreted Tunnel Route Geological Profiles	1: 2,500H, 1: 250V
MM0209/E5	<i>Bigga to Yell</i>	
	Interpreted Tunnel Route Geological Profiles	1: 2,500H, 1: 250V
MM0209/6	<i>Shetland Mainland to Yell</i>	
	Distribution of Superficial Sand Deposits	1: 5,000H



4.1 BATHYMETRY

Water depths have been influenced and shaped by the development of deep-cut, glaciated channels which have produced steeply dipping sides to the marine channels and relatively flat-lying, broad, channel bases. Both the eastern and western channels of Yell Sound, on either side of Bigga, show a similar topography. Soundings were obtained as far shorewards as safe manoeuvrability of the survey vessel was allowed; a least depth of 2.5m below CD was recorded off the south Shetland Mainland shore and 4.5m off the east shore of Bigga. Steep slopes (1:4), on channel sides, combined with extremely irregular, rocky foreshores meant that it was not consistently possible to obtain data less than 5m below CD.

Maximum water depths of 50.6m and 48.8m below CD were found within the channel troughs on the west and east sides of Bigga, respectively. Between Shetland Mainland and Bigga, the flat-lying channel base varies in width from 200m to 350m, being at its broadest to the south. Conversely, the channel between Bigga and Yell is 450m wide at its broadest to the north; this narrows to less than 150m towards the south.

To the southwest of Bigga, shallower water depths coincide with the presence of thick sand deposits. Water depths reach a minimum of 30.1m with an accumulation of sands – up to 15m thick – occupying the seabed.

The average seabed profile above the route of the proposed tunnel between Shetland Mainland and Bigga consists of an initial slope of 1:10 off Shetland Mainland, followed by a 400m wide, flat-lying channel base, located at approximately 44m below CD. Progressing eastwards, the seabed rises at a gradient of 1:8, towards Bigga.

For the tunnel route between Bigga and Yell, the seabed profiles exhibit a 1:11 slope falling from Bigga, followed by a channel approximately 300m wide at its base at approximately 48.1m below CD. The central channel between Bigga and Yell is not capped by superficial sands, although coarse marine, or glacial, materials do appear to overlie rockhead. The gradient of the flank rising from the channel towards Yell is a more gentle 1:15, and some superficial sands are present on the channel side.

Both the northern and southern route tunnel options have a similar bathymetric profile.



Contoured bathymetry and soundings are presented on Drawing Nos MM0209/W1 and MM0209/E1. Data Examples of echo-sounder records are provided in Appendix 3.

4.2 SEISMIC PROFILING

Information from the 'boomer' survey has been used to provide an interpretation of the sub-seabed geology of the Yell Sound site using an assumed acoustic velocity of 1675m/s for the unconsolidated, superficial sediments.

Overburden thickness has been differentiated into a medium to coarse-grained SAND which displays sand ripple and megaripple bedforms and a clayey, sandy GRAVEL/gravelly SAND that may well have either marine or glacial origins. The sand unit is sparsely developed, being concentrated into isolated thick deposits in the south of the area. Thinner deposits floor parts of the central channels. The glacial and/or coarse marine deposits overlie rockhead, infilling troughs and depressions within the rock and carpet the central channels in Yell Sound. The coarse overburden thins towards the land, where rock outcrops directly at the seabed.

The results of the geophysical interpretation are presented in the following Charts:

Drawing Nos. MM0209/W2 & E2: present the thickness of the upper unconsolidated sediments, which are likely to comprise medium to coarse sands.

Drawing Nos. MM0209/W3 & E3: present the thickness of the upper sand unit combined with that of the sandy, gravelly clay, to provide a total thickness of overburden overlying rockhead level

Drawing Nos. MM0209/W4 & E4: have been produced by addition of the soundings data to the total overburden thickness, to obtain a Contoured Surface of the Top of Rockhead below CD.

Ground conditions along the proposed tunnel routes are presented in the form of interpreted geological profiles along the northern and southern routes. These routes have been scaled from a drawing provided by the Client, but with the information available on the enclosed charts it is possible to produce additional profiles along any alternative route of interest. For the sake of clarity all isopachytes are presented as contoured plots. Thickness values have been logged for



every fix point of the survey in order to derive these charts and these values can be provided, should they be required.

Finally, an overview map (Drawing No. MM0209/6), at a scale of 1: 5,000, presents the distribution of the superficial sand deposits in order to assist volume calculations in case the sand resources can be utilised on any relevant future projects in the area.

4.2.1 Sedimentary Overburden

The seismic records enabled the identification of two sedimentary units overlying the rockhead: an upper marine sand unit and a coarser textured, more chaotically bedded unit - interpreted to be either a mixed glacial deposit or very variable, marine sediments.

- **Sand**

Reference should be made to Drawing No. MM0209/6, presented at a scale of 1:5,000, for an overview of the sand deposits within the survey area and to Drawing Nos. MM0209/W2 to E2, Isopachyte of Sand, presented at a scale of 1: 2,500.

- **Sand Bodies 1 & 2 (SB1 and SB2)**

The sands present in Sand Bodies 1 and 2 (SB1 and SB2), display low amplitude (0.3m), short wavelength (about 5m crest-to-crest) sandwaves at seabed; these grade into units which are either sub-parallel bedded or cross-bedded. Progressing laterally, bedding character is discontinuous, with foresets terminating abruptly and showing interdigitation with horizontally bedded sands. Both sand bodies are thick developments, reaching a maximum of 16m for SB1 and 10m for SB2.

SB1 appears to consist of an upper unit, which is sub-parallel to the seabed contours and persists to an approximate depth of 5m; this overlies a core of material which appears to comprise a drape over a central high point, roughly coincident with the thickest development of the unit (Appendix 3, Data Examples). The centre of this core may be composed of coarse gravels, cobbles or even boulders which have acted as a focus for the accumulation of marine sands around the denser/coarser core.



Sand Body 3

Sand Body (SB3) forms a long sand deposit infilling the central channel axis between Bigga and Yell in the north and forming a thicker deposit on the channel flank close to Yell. In the north, well developed sand waves are seen, having maximum amplitudes of 1m from crest to trough and 10-20m wavelengths between crests. The sandwaves are asymmetrical, indicating a sand transport direction from SE to NW, and trains of subordinate megaripples have accreted on to the sandwaves to produce accumulations of sand, up to 8m thick. Progressing to the south, the sand body changes character, to become sub-parallel bedded with occasional ripple and megaripples bedforms at the seabed. The megaripples include both symmetrical and asymmetrical types, the latter, interestingly, display a sand transport direction from NW to SE – the opposite of the same sand body to the north. This raises the possibility of a cyclic sedimentation pattern interconnecting the sands within this section of Yell Sound, possibly maintaining a state of equilibrium. (It could, alternatively, simply be a function of the structures responding to the prevailing tidal stream at the time, with the transport direction changing on each tide.) The results of a single survey are not sufficient to draw any valid conclusions, however, and additional studies would be required should the sand dynamics of the Sound be considered an important issue. SB3 reaches a maximum thickness of 8m in the north and 7m in the south. The average, overall thickness of SB3 is 3.1m.

Sand Body 4 (SB4)

Sand Body 4 (SB4) is an elongate sand deposit flooring the channel trough between Shetland Mainland and Bigga. It is characterised by very regular, symmetrical sandwaves typically 10m in wavelength, crest-to-crest, and with amplitudes of 0.5m. Trains of sandwaves and megaripples indicate transport directions for the marine sands, and the symmetry indicates that, at the time of survey, neither north nor south directions were dominant. It is also evident that the megaripples present at seabed overlie former trains of megaripples as relict bedforms, providing a maximum total thickness of 4m. In general, the sand deposit is quite thin, averaging 1.5m overall.



Sand Body SB5

This varies from approximately 200m in width, at the northern survey limit on the east side of Bigga and extends to at least 300m northward, possibly persisting beyond the survey limits. The sand is an acoustically near-transparent unit with small current ripples of less than 0.2m amplitude and very short wavelength. The maximum sand thickness is 4m and average thickness is 1.1m.

Sand Body SB6

This is a small deposit, 100m wide, located off the Shetland Mainland to the north of the survey area. It extends for about 200m, it is elongated in a north-south direction, being confined to shallow waters of less than 15m. Small current ripples up to 0.2m high are apparent on NE-SW lines, indicating that the sand is possibly a local supply from nearby beach reworking/transport and therefore of different provenance to the other sand bodies identified in the survey area. The unit is acoustically transparent, apart from faint bedding laminae, which are sub-parallel, and is likely to be a fine sand or silt, possibly containing shell fragments. Thickness of the unit averages 1.1m with a maximum of 3.5m.

Glacial/Coarse Marine Deposits

This unit is an infill deposit, seen as a drape of sediments lying directly over the underlying rockhead. Bedding laminae are only present where these deposits contain appreciable clays and sands and this tends to be most apparent within the central channels of Yell Sound or in the upper sequences on the channel flanks. The most typical characteristic of the infill is to display a chaotic assemblage of coarse gravels, cobbles and clayey sands showing on the seismic records as a dense acoustic signature with numerous diffractions, (see Appendix 3, Data Examples). No bedding laminae are apparent and the contact to underlying rockhead is indistinct, owing to multiple diffractions on the records. The chaotic nature of the internal structure suggests that these deposits are more likely to be of glacial, or fluvio-glacial, origin.

Maximum thickness of the glacial fill appears to be within the deep channels within Yell Sound, which appear to be fault controlled. Between the Shetland Mainland and Bigga, south of Bigga, a total thickness of overburden of 20m is found. In fact, 16m of this comprises the upper sand, with only 4m of fill beneath. Distribution of the glacial fill appears to be



controlled by the structure and topography of the underlying rockhead. Active glaciation of the basement rocks took place during the Devensian Glaciation, resulting in downcutting, abrasion and polishing of the existing metamorphic rocks by ice action. On melting of the ice, the bedload of rock debris combined with it would have been deposited preferentially into topographic lows and especially into deeper crevices and troughs marking the positions of former fault planes

Drawing Nos. MM0209/W3 and E3 illustrate the total thickness of overburden comprising the upper sand and the glacial deposits within the survey area. These charts are contoured at 2m intervals, which serves to demonstrate the locations of several faults which have affected the underlying rocks. Although the overlying overburden is not faulted, the materials do show evidence of differential settlement in the vicinity of faults and the influence of the geometry of the underlying bedrock surface upon that of the infill and draping, later sediments is clearly apparent. Many of the offshore faults can be equated to faults located on the foreshore, identified during the geological mapping exercise. The locations of these faults are of special relevance to the future tunnelling programme as they are likely to extend to depth within the basement rocks and may prove to be localised areas of weakness.

4.2.2 Rockhead Level

On the seismic records the unit defined as 'top of rockhead' displays a dense, acoustic character, with numerous diffractions and an irregular, 'saw-tooth' topographic expression.

Seismic penetration below the top of this unit is very limited, demonstrating that the rock strata are likely to be hard and mostly in a fresh state (as opposed to being deeply weathered). However, in areas where glacial till overlies rockhead much of the seismic energy is absorbed prior to reaching the rock so it is possible that fresh rockhead levels may lie deeper in such areas, with the weathered, upper horizons only having been identified.

Over much of the survey area, rock outcrops at the seabed and this is best illustrated on Drawing Nos. MM0209/W3 and E3. Between Shetland Mainland and Bigga, rocks outcrop for up to 500m from the Shetland Mainland foreshore, although occasional faults have resulted in some pockets of marine sediment cover or glacial fill. On the west side of Bigga, rock outcrops are more



spasmodic; aureoles, 50m or so in width, fringe many of the headlands. To the south and east side of Bigga, rock outcrops more extensively: up to 1km of rock outcrops extending eastwards from the southern tip of Bigga are broken only by a narrow, 100m wide channel, and the entire east side of Bigga is fringed by rock outcrops extending into the Sound by up to 500m. Off Yell, rock outcrops are strongly fault controlled by a series of NNE-SSW trending wrench faults so that rock outcrops fringing the shore vary between 50m and 300m in width. (A 'trend' is the azimuth of the line of intersection between a dipping anisotropy – such as a foliation plane or fault – and another surface, such as seabed or that of the ground.) Fault controlled inliers of rock are also found within the channels.

Anticipated rockhead levels along the proposed tunnel routes are depicted on the interpreted seismic sections (Drawing Nos. MM0209/W5 and E5). In addition, reference should be made to Drawing Nos. MM0209/W4 and E4, Contoured Surface of Top of Rockhead.

The rockhead contours presented show the depths below CD to the top rockhead level, determined from the seismic survey. These show a polished rock front, dipping steeply at up to 1: 6 towards the central channel which was gauged out by ice action during the last glaciation. Beneath both channels of the Sound, to each side of Bigga, the base of the channel/top of rockhead is as deep as 60m below C.D or 10-12m below the deepest current water depth.

Between Shetland Mainland and Bigga, several faults were located from the marine seismic data. A cluster of five faults, exhibiting a N-S strike, occurs on the flanks of the channel beside Bigga and extends into the central channel region. Small amounts of downthrow and lateral movements are apparent within the overburden cover, possibly indicating differential settlements which have occurred post-sedimentary deposition. Reactivation of the old fault planes is not considered likely, although it cannot be altogether discounted.

To the south of this section of route a complex cluster of three faults is located - also within the central channel area, where a pair of faults trending NNW-SSE and NW-SE intersect and form a closure with a N-S trending fault.

The proposed tunnel route from Shetland Mainland to Bigga does not appear to traverse any significant faults along the marine route although the geological mapping of the foreshores found some evidence of faulting on the shorelines above the landfall tunnel routes.



Any proposed tunnel profile - depending on the in-situ frequency and degree of openness of faults and joints within the rock in the central channel area - should maintain a level of at least 60m below Chart Datum below this section of the marine route, if a reasonable rock cover is to be preserved. This would allow a rock cover of 12m (measured from tunnel roof), to base of overburden and about 15m to seabed level. A schematic illustration of the tunnel route is presented on Drawing No MM0209/W5 at 60m below CD. (See also Appendix 3, Data Examples). As we have no knowledge of the planned tunnel route incline approaching Shetland Mainland we have, as an example, maintained the route profile at a level of 60m below CD for the whole of the route. The presented profiles can be modified to present the actual planned tunnel route when such information becomes available.

Between Bigga and Yell, the geological picture appears more complex, with rockhead contours being disturbed by a set of at least three, NNE-SSW trending wrench faults which appear to radiate from observed faults in the south of Yell. The faults are primarily dextral, with evidence for overburden displacements of up to 10m. This fault direction appears to be a more recent set than those faults associated with the Sound axis-parallel Nesting Fault, and evidence for possible fault reactivation cannot be discounted. In addition, a prominent fault extends for over 800m from Bigga to the south of the area. Over the marine section of the route this primarily affects exposed rock. The central channel region of the Sound is also faulted by a set of faults trending N-S or NNW-SSE, and following the central channel axis. These faults coincide with the Nesting fault set which is thought to be the oldest set, and probably contributed significantly to the formation of the Sound. Up to 16m infill of glacial deposits and sands now overlie the fault planes, which are likely to extend deep into the rock.

The proposed tunnel route between Bigga and Yell will be affected by a major fault in the central channel at chainage 630 on the northern route and chainage 640 on the southern route. A proposed tunnel planned at 60m below CD along this section of the route would only have 5m of rock cover or about 12m to breaking out at seabed. As this is also coincident with a fault with the possibility of weak and fractured rock units locally, it may be advisable to consider a deeper



alignment for the tunnel route in this section. Drawing No. MM0209/E5 presents a schematic tunnel profile at 60m below CD. The angle of the tunnel's approach to Yell is unknown at this time.

Borehole correlation would be an essential prerequisite to check the mechanical condition of the rock and for correlation with the seismic data.



5.0 CONCLUSIONS

- 5.1 Yell Sound is a NW-SE orientated sea passage between the Shetland Mainland and the island of Yell. The sound is split into two – an east and a west sound - between which lies the elongate island of Bigga. A major geological boundary occupies the long axis of Bigga, separating metamorphosed sedimentary rocks to the east, from granitic, intrusive rocks to the west.
- 5.2 Both sounds are sites for significant faulting; the eastern sound is dominated by the NNW-SSE trending Nesting Fault, which has been posed as being a fundamental crustal fracture and a possible extension to the Great Glen Fault (within which is sited Loch Ness). The rocks of the western sound contain numerous – though, perhaps, less fundamental - intersecting faults, having N-S, NNE-SSW and ESE -WSW orientations. The Nesting Fault is orientated sub-parallel to the axis of the western sound, whilst other faults do trend across both sounds.
- 5.3 Intense fracturing was seen at the southern tip of the island of Bigga, where the sound bifurcates. The Shetland Mainland to Bigga proposed tunnel route appears to be free of major faults in the marine section. A tunnel sunk at a level of 60m below CD would ensure a 12m head of rock cover below the most critical channel base region.
- 5.4 The Bigga to Yell proposed tunnel route would be affected by a fault plane crossing the route between chainage 630 and 640. A proposed tunnel, sunk at a level of 60m below CD, would have only 5m of rock cover - or 12m of rock and overburden combined - below seabed level. As this is also coincident with a fault there is the possibility of weak or brecciated rocks in this vicinity.
- 5.5 In general, rockhead lies very close to the seabed or forms extensive areas of outcrop extending into both channels of the Sound.
- 5.6 The sedimentary overburden is concentrated in the central channel basin and adjacent flanks and consists of up to two sedimentary units overlying rockhead: The uppermost unit consists of medium grained SAND which displays ripples and/or megaripples at seabed.



The sands occur as a minimum of six, distinct sand bodies:

- two large deposits which infill the central channels,
- two, thick, cross-bedded deposits, located to the south between Shetland and Bigga, and
- two small deposits, located close to the eastern shores of Shetland and Bigga in the north of the area.

Total sand volume is in excess of 6 million cubic metres.

- 5.7 The second sedimentary unit consists of a chaotic assemblage of coarse gravels, cobbles and clayey sands and is considered probably to be a GLACIAL TILL deposit. This material directly overlies rockhead and infills any troughs and former fault planes within the rock.
- 5.8 The bathymetry of the survey area has been influenced by the last glaciation to produce a steeply dipping seabed with slopes up to 1:4 and a broad, flat-lying channel base comprising Yell Sound. Similar bathymetric profiles exist within the Sound on both sides of the central island of Bigga.
- 5.9 Maximum water depths of 50.6m below CD were found in the channel between Shetland Mainland and Bigga and of 48.8m below CD in the channel between Bigga and Yell.
- 5.10 A reconnaissance level geological mapping exercise was undertaken. This revealed that whilst there were structural similarities between the exposures visited on the Shetland Mainland and throughout the island of Bigga, marked differences were seen to the east of the Nesting Fault on the island of Yell.
- 5.11 The mapping exercise provided evidence of cross-sound faults along each of the shorelines and photographs have been provided which demonstrate the effects that these can have upon the topography. These can vary between scarcely visible changes on the vegetated land surface to wide, deep gullies which can be traced for considerable distances inland, from the shorelines. It is the case that where such structures are present within the sounds, similar effects upon intact rockhead topography may be



anticipated. Where gullies have been formed beneath the sounds, they have been infilled by mixtures of glacial and marine sediments.

- 5.12 Rockhead has been sculpted by glaciation, and preferential erosion of materials close to faulted areas of rock has been responsible for the very existence of the Sound.
- 5.13 Sections have been prepared along the routes which are, almost certainly, preliminary. Further sections, along alternative routes could be prepared, if required.



6.0 RECOMMENDATIONS

- 6.1 Owing to the potential significance of faulting within the tunnel corridors, a considerably more detailed geological mapping programme, supported by specifically flown, helicopter-borne, stereo-vertical and stereo-oblique air photography is recommended. Such an exercise would almost certainly provide a lot more information, and be of considerable value, in predicting the geometries and condition of the rock structures within the sounds.
- 6.2 Geotechnical investigations using rotary core drilling should be undertaken on Shetland Mainland, Bigga and Yell to sample down to the planned tunnel route and to assess the geotechnical properties of the rocks.
- 6.3 Ideally, a borehole investigation of the rocks in the central channels of the Sound along the line of the proposed tunnel should also be considered. However, due to the extreme water depths of 50m, combined with strong sea currents and uncertain weather conditions such an undertaking would be likely to be extremely expensive.
- 6.4 Should marine geotechnical investigations prove too difficult, another option might be a directional drilling programme from land to follow the proposed tunnel routes as a pre-requisite for final route selection.
- 6.5 Substantial sand reserves within the survey area may give an opportunity for use of such aggregate for any future projects requiring fill for reclamation projects, alternatives to the proposed tunnel, industrial usage etc. With a potential reserve of over 6 million cubic metres (Refer to Section 7, Volume Estimates) there is sufficient material to give consideration to the establishment of causeway links between Shetland Mainland to Bigga and from Bigga to Yell. If this option were of interest then Caledonian Geotech Associates would be able to advise on the design and inception of a suitable alternative scheme.
- 6.6 Although the 60m below CD level for tunnel construction may be suitable for the Shetland Mainland to Bigga section of the route, a deeper profile may be advisable for the section of the route between Bigga and Yell. This is because of a prominent fault within the channel



with evidence of possibly weak, brecciated rocks adjacent to the fault which may extend deep within the rock.



7.0 SAND VOLUME CALCULATIONS

As the survey has located sizeable sand deposits within Yell Sound an estimate is given of potential volumes of sand in case there is a future need for sand as a source of fill, reclamation or for industrial aggregate usage. The various sand bodies in the survey area are shown on Drawing No. MM0209/6 and sand volumes have been derived by averaging values over 50m square grids over isopachtye charts to obtain a maximum likely resource.

TABLE 1 -VOLUME CALCULATIONS

Sand Body	Location	Water Depth(m)	Area of Sand (m ²)	Volume of Sand (m ³)	Average Sand thickness	Comments
1	South of Bigga	35-45	370,000	1,812,000	4.8m	Coarse, cross-bedded sand up to 16m thick
2	South Shetland shore	25-45	355,000	1,565,000	4.4m	Cross-bedded sand. Up to 10m thick.
3	Bigga to Yell channel	15-47	620,000	1,931,000	3.1m	Megarippled sand in north, rippled sand in south near Yell.
4	Shetland to Bigga channel	30-50	535,000	809,000	1.5m	Megarippled sand up to 4m thick but generally thinner. Confined to deep water channel.
5	East of Bigga	15-40	65,000	142,000	2.1m	Small, sand rippled deposit.
6	Off east Shetland Mainland	5-15	25,000	37,000	1.4m	Small, rippled fine sand/silt sand.
TOTAL			1,970,000	6,296,000	3.1	

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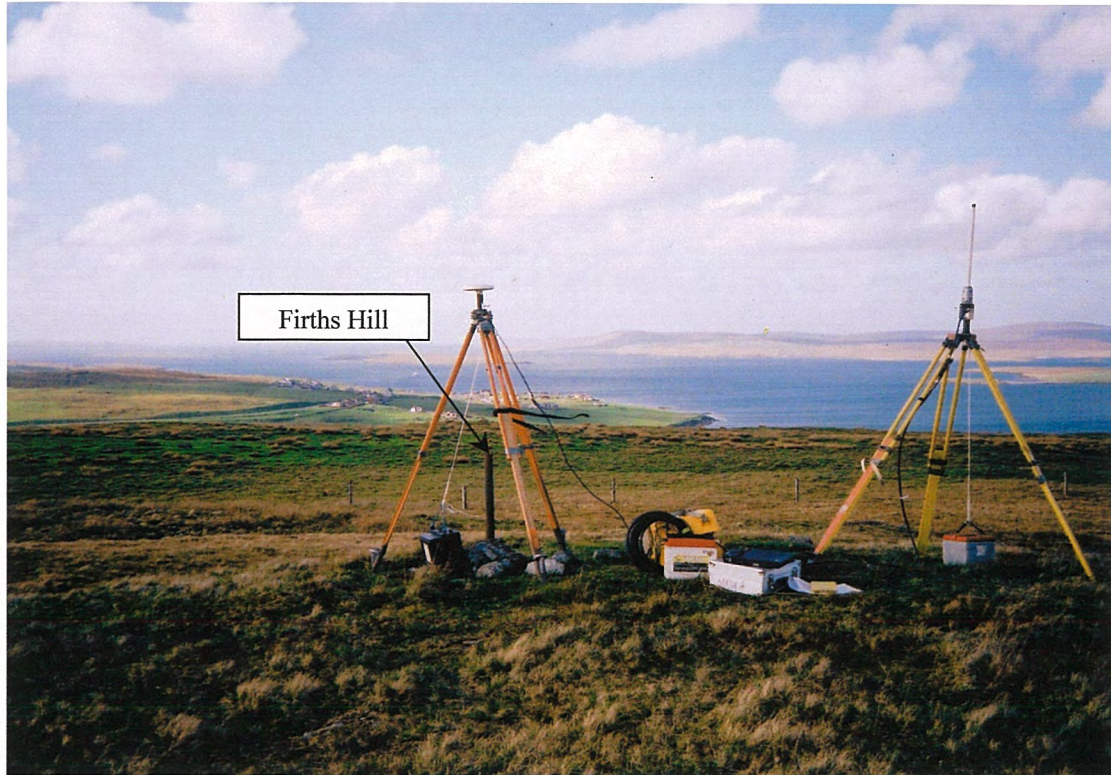
Client SHETLAND ISLANDS COUNCIL
Title YELL SOUND TUNNEL PROJECT
Project No. MM0209



APPENDIX 1 SURVEY STATION DESCRIPTIONS

Station Name:
Area/ Location:

Firths Hill
West Sandwick, Yell, Shetland
O.S. 1:50 000 Sheet No: 2

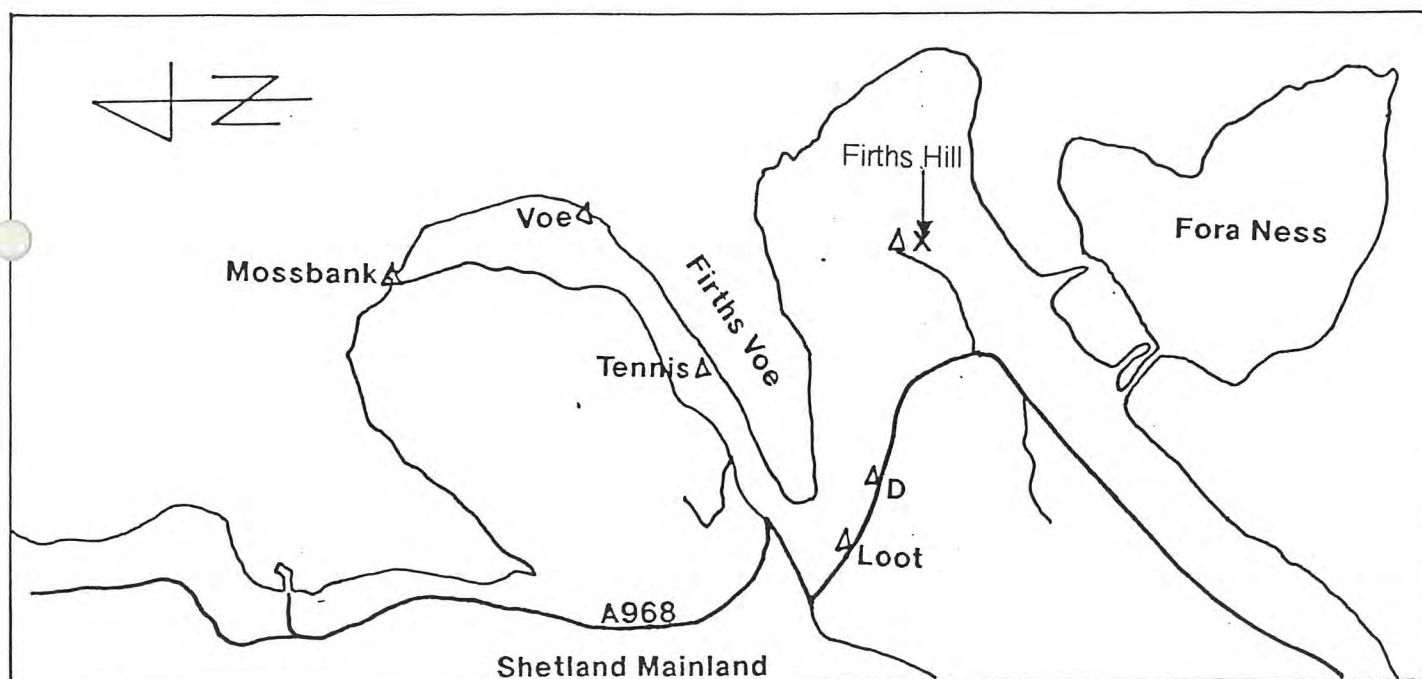


SURVEY STATION DESCRIPTION

Station Name: Firths Hill
Area/Location: Firths Hill, Shetland Mainland
O.S. 1:50 000 Sheet No: 2
Description of mark: Nail in 50mm diameter concrete-filled pipe
approximately 0.5m above ground level
Location of station: Near the top of Firths Hill on the left of a track
approximately 5m past a microwave station.
Date of survey: 12/05/02
Surveyed by: Caledonian Geotech Ltd.
Method: Closed RTK DGPS traverse from Swinister Hill TP
Accuracy: Plan: $\pm 1\text{cm}$; Level: $\pm 1\text{cm}$
Access: Vehicular access via a track leaving the A968 at Oldhall
and leading to a microwave station at the top of Firths
Hill.

Co-ordinate Information:

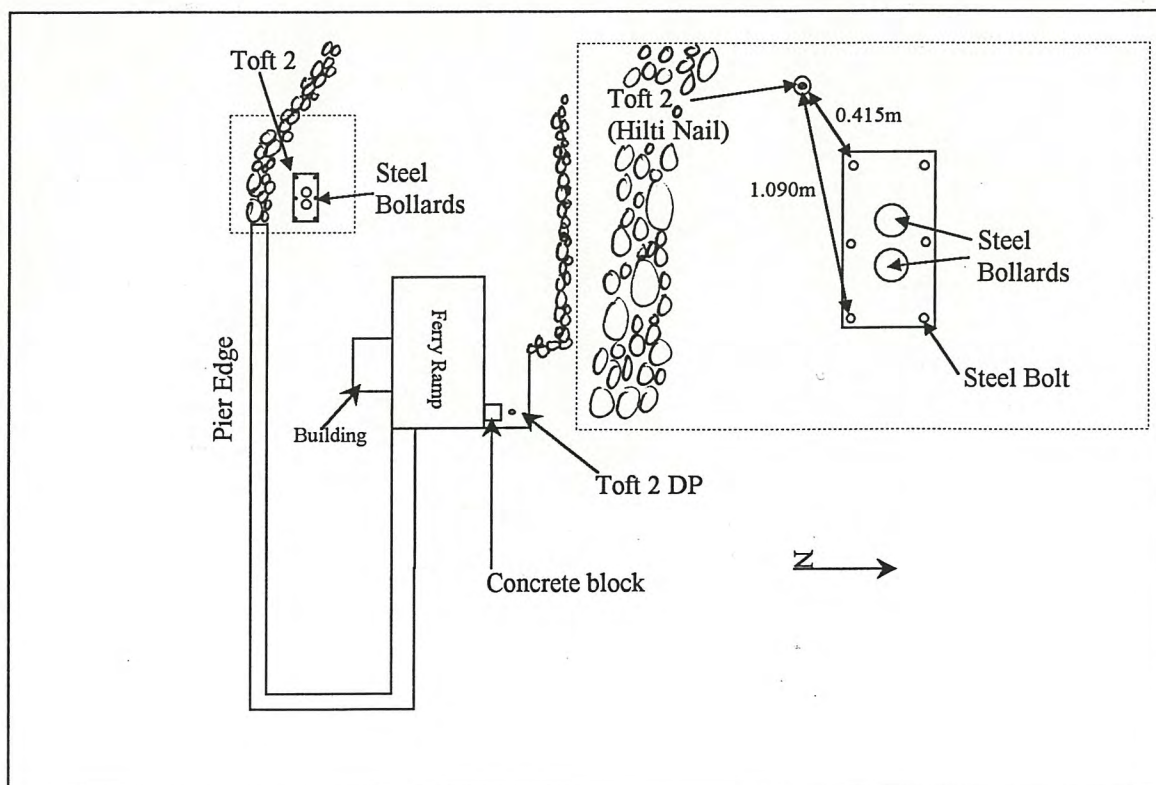
Spheroid: Airy 1830
Vertical Datum: O.D. Lerwick
Projection: OSGB36
Co-ordinates: E:445244.62 N:1173343.27
Lat: $60^{\circ} 26' 30.94200\text{N}$ Long: $01^{\circ} 10' 39.91800\text{W}$
Elevation: 117.500 O.D





SURVEY STATION DESCRIPTION

Station Name: Toft 2
Area/Location: Toft Pier, Shetland Mainland
O.S. 1:50 000 Sheet No: 2
Description of mark: Hilti nail painted yellow
Location of station: 1.5m in from the southern edge of Toft Pier just before the first steel bollards reached when approaching the pier from the land.
Date of survey: 12/05/02
Surveyed by: Caledonian Geotech Ltd.
Method: Closed RTK DGPS traverse from Swinister Hill TP
Accuracy: 0.05m
Access: Drive towards the ferry terminal and park to the right (south) of the ferry terminal barrier on Toft Pier.
Co-ordinate Information:
Spheroid: Airy 1830
Vertical Datum: O.D. Lerwick
Projection: OSGB36
Co-ordinates: E:443701.18 N:1176142.10
Elevation: 2.096m O.D.



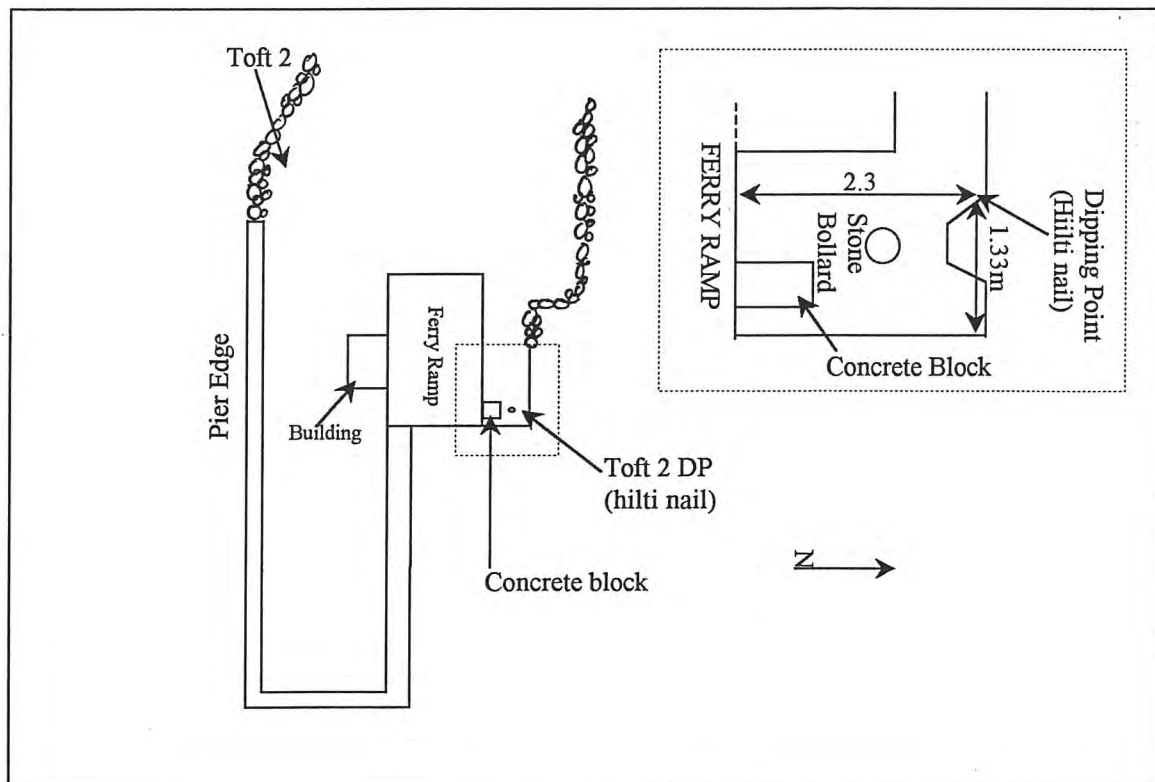


SURVEY STATION DESCRIPTION

Station Name: Toft 2 DP
Area/Location: Toft Pier, Shetland Mainland
O.S. 1:50 000 Sheet No: 2
Description of mark: Hilti nail in landward corner of indentation in North Eastern corner of Toft Pier.
Location of station: North Eastern corner of Toft Pier.
Date of survey: 13/05/02
Surveyed by: Caledonian Geotech Ltd.
Method: Closed level traverse from Toft 2 survey station.
Accuracy: 0.01m
Access: Drive up to the ferry terminal barrier and park on the left (northern side) in front of the ferry timetable notice board. Follow a narrow concrete walkway situated to the north of the ferry terminal ramp seaward.

Co-ordinate Information:

Spheroid: Airy 1830
Vertical Datum: O.D. Lerwick
Elevation: 1.964 m O.D.



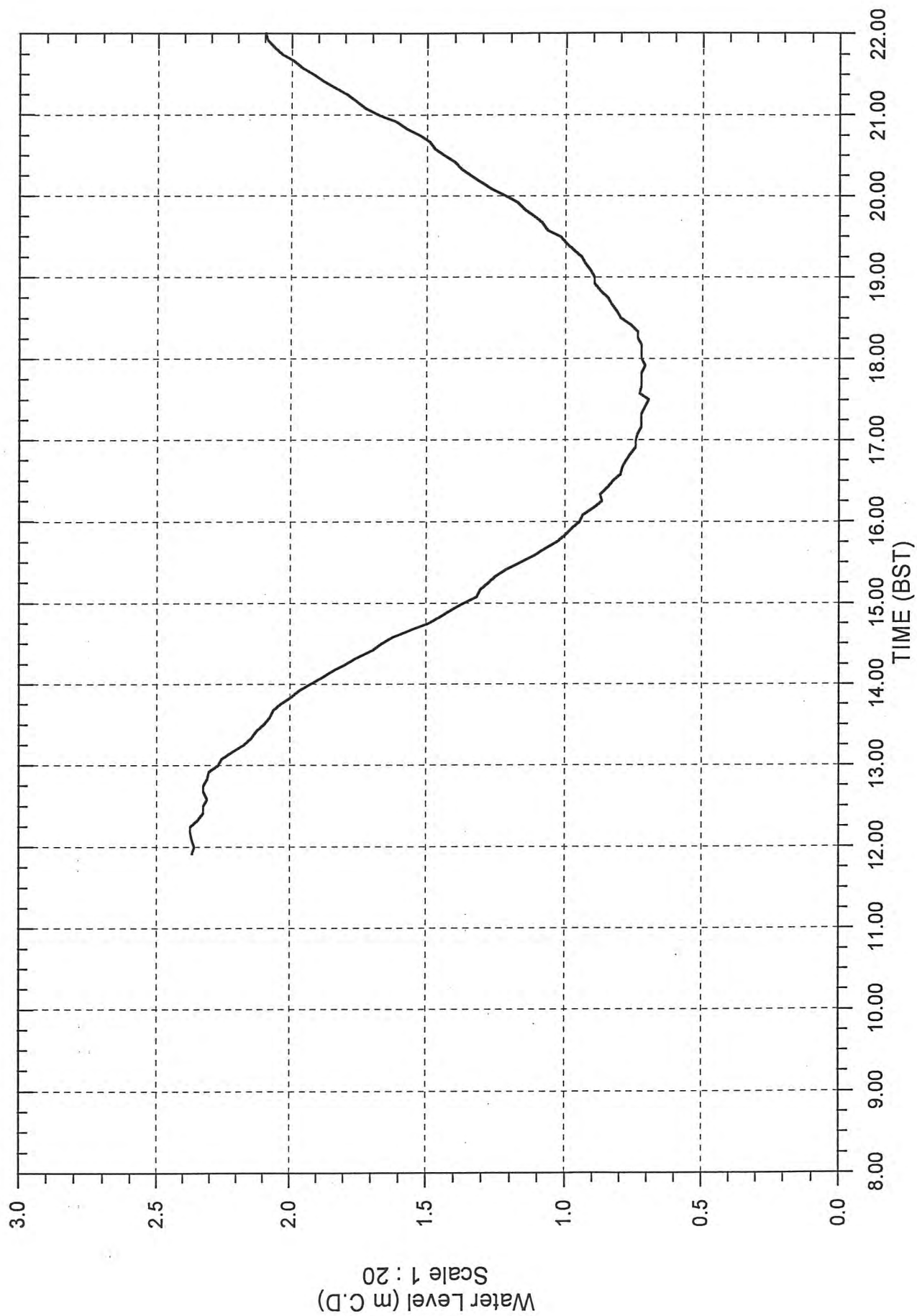
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Client SHETLAND ISLANDS COUNCIL
Title YELL SOUND TUNNEL PROJECT
Project No. MM0209

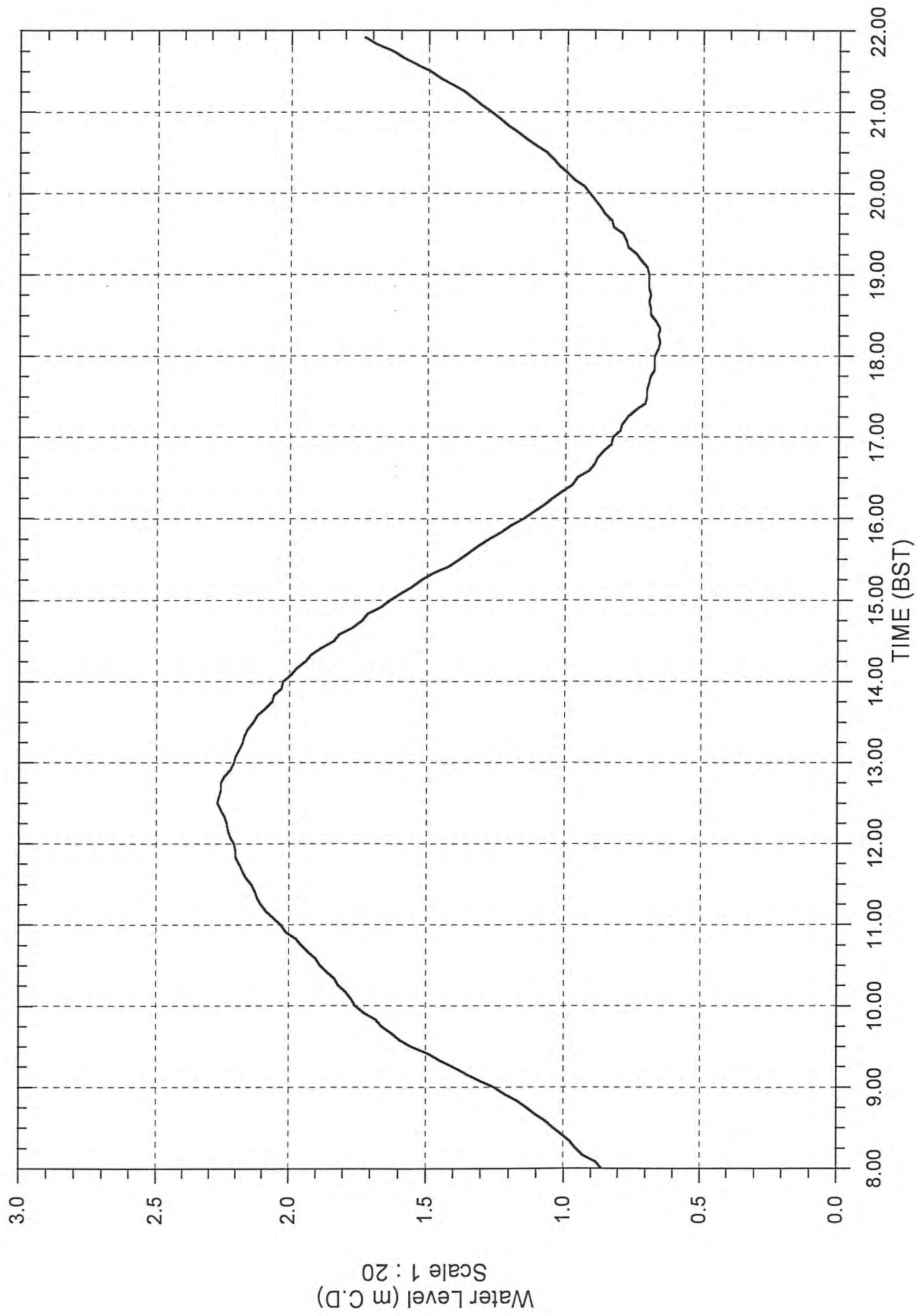


APPENDIX 2 TIDE CURVES

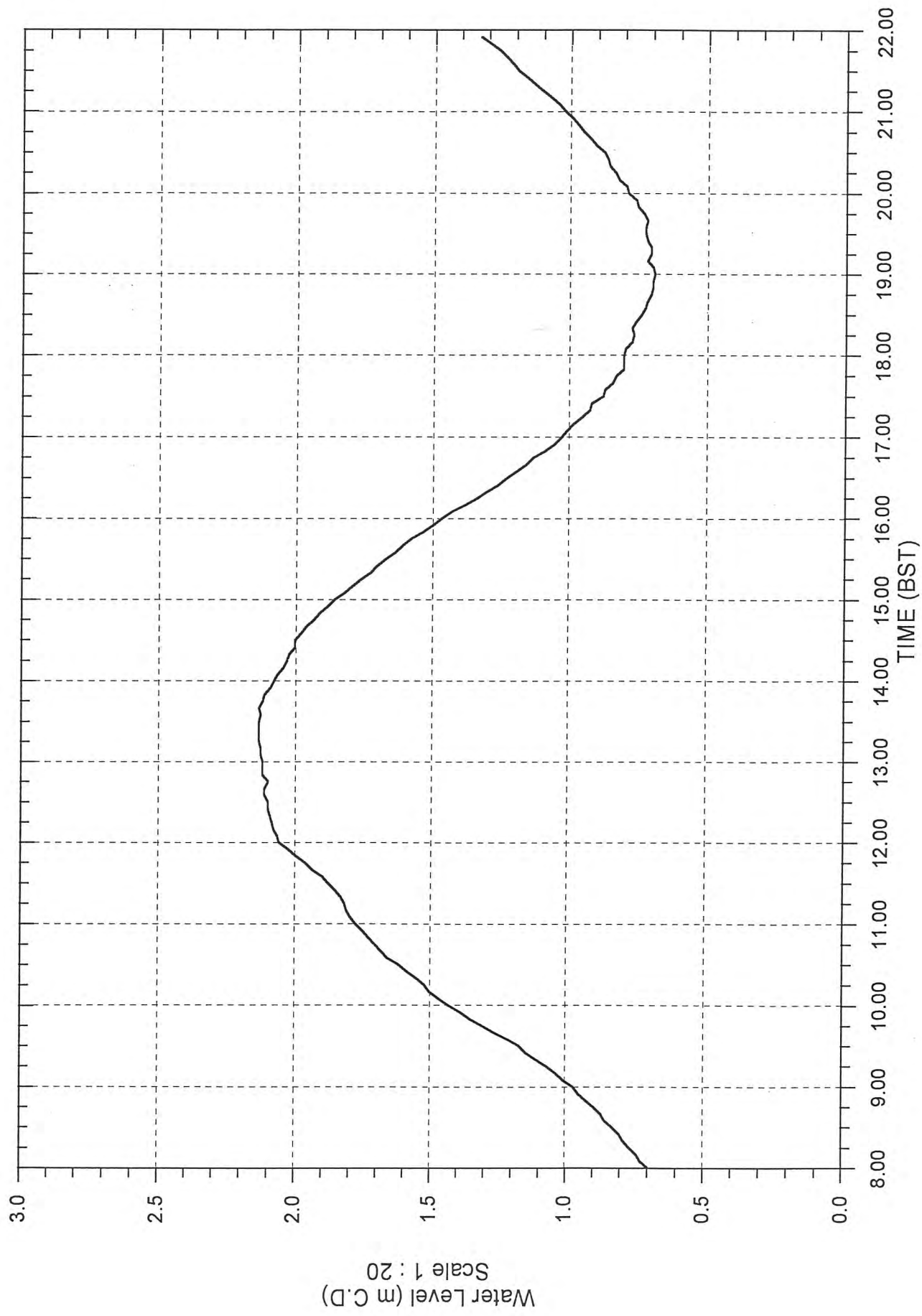
Caledonian Geotech Ltd MM0209 - Shetlands Islands Council -
Tide Gauge 0184 - Water Levels Reference to Admiralty Chart Datum 14/05/02



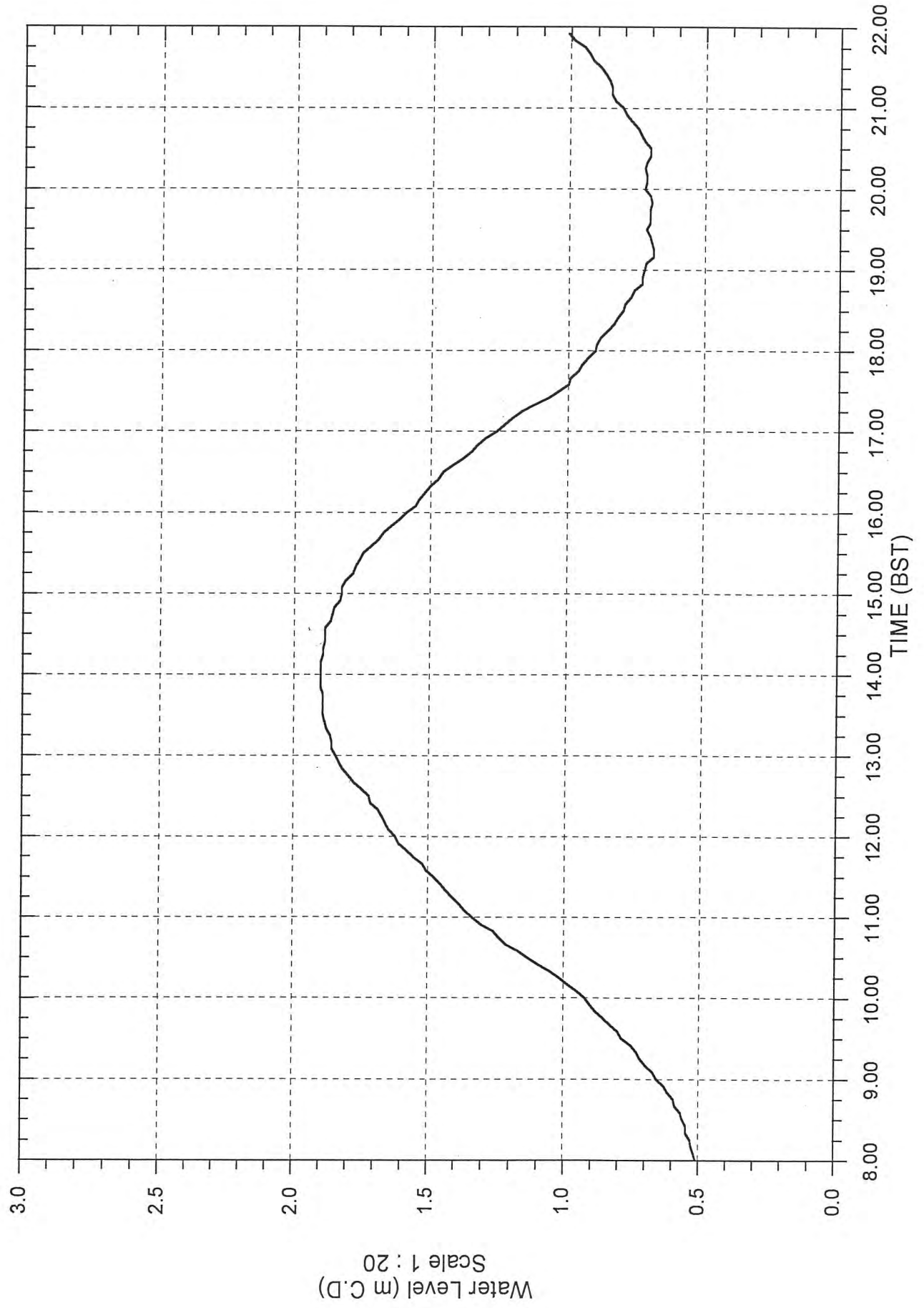
Caledonian Geotech Ltd MM0209 - Shetlands Islands Council -
Tide Gauge 0184 - Water Levels Reference to Admiralty Chart Datum 15/05/02



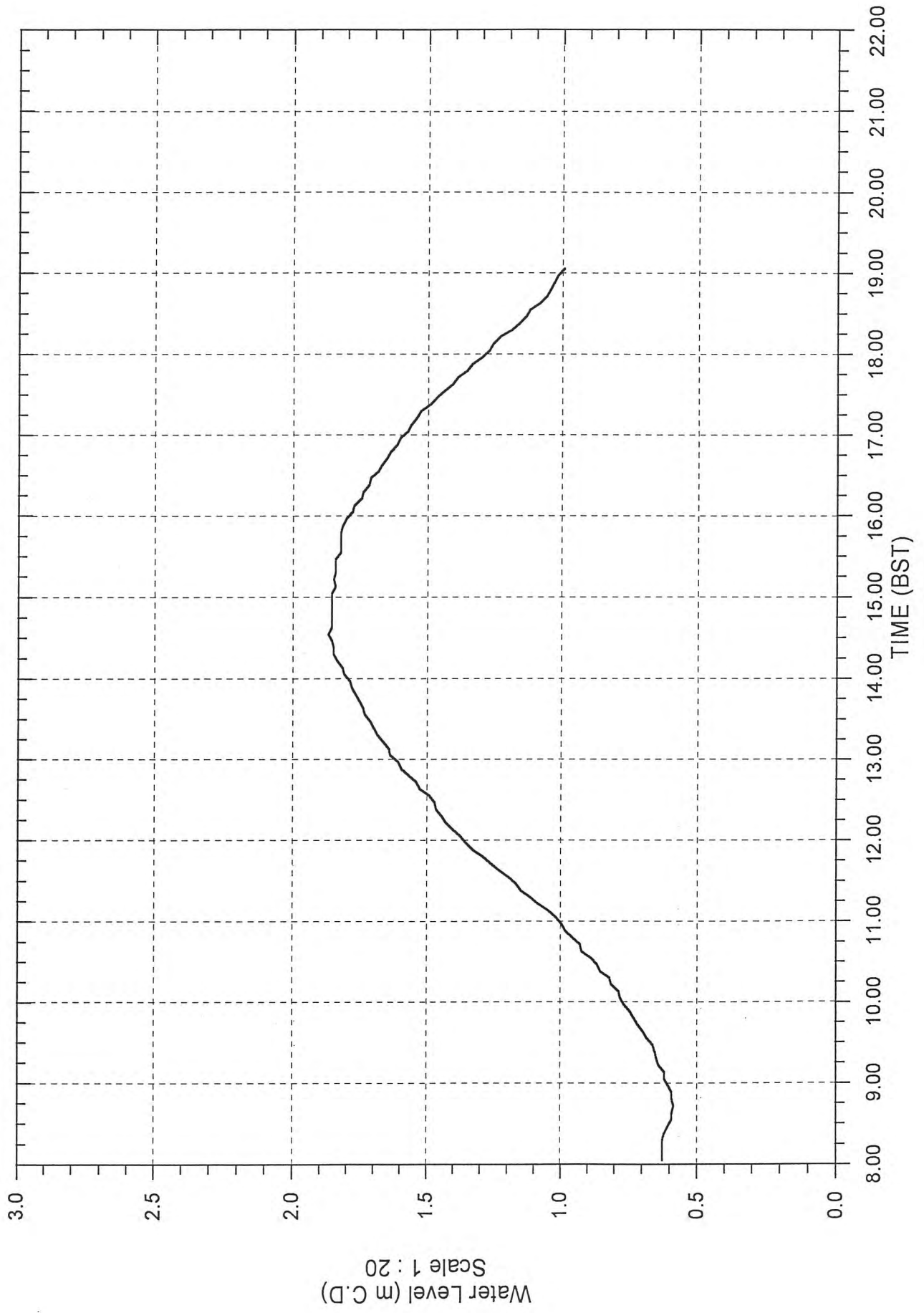
Caledonian Geotech Ltd MM0209 - Shetlands Islands Council -
Tide Gauge 0184 - Water Levels Reference to Admiralty Chart Datum 16/05/02



Caledonian Geotech Ltd MM0209 - Shetlands islands Council -
Tide Gauge 0184 - Water Levels Reference to Admiralty Chart Datum 17/05/02



Caledonian Geotech Ltd MM0209 - Shetlands Islands Council -
Tide Gauge 0184 - Water Levels Reference to Admiralty Chart Datum 18/05/02

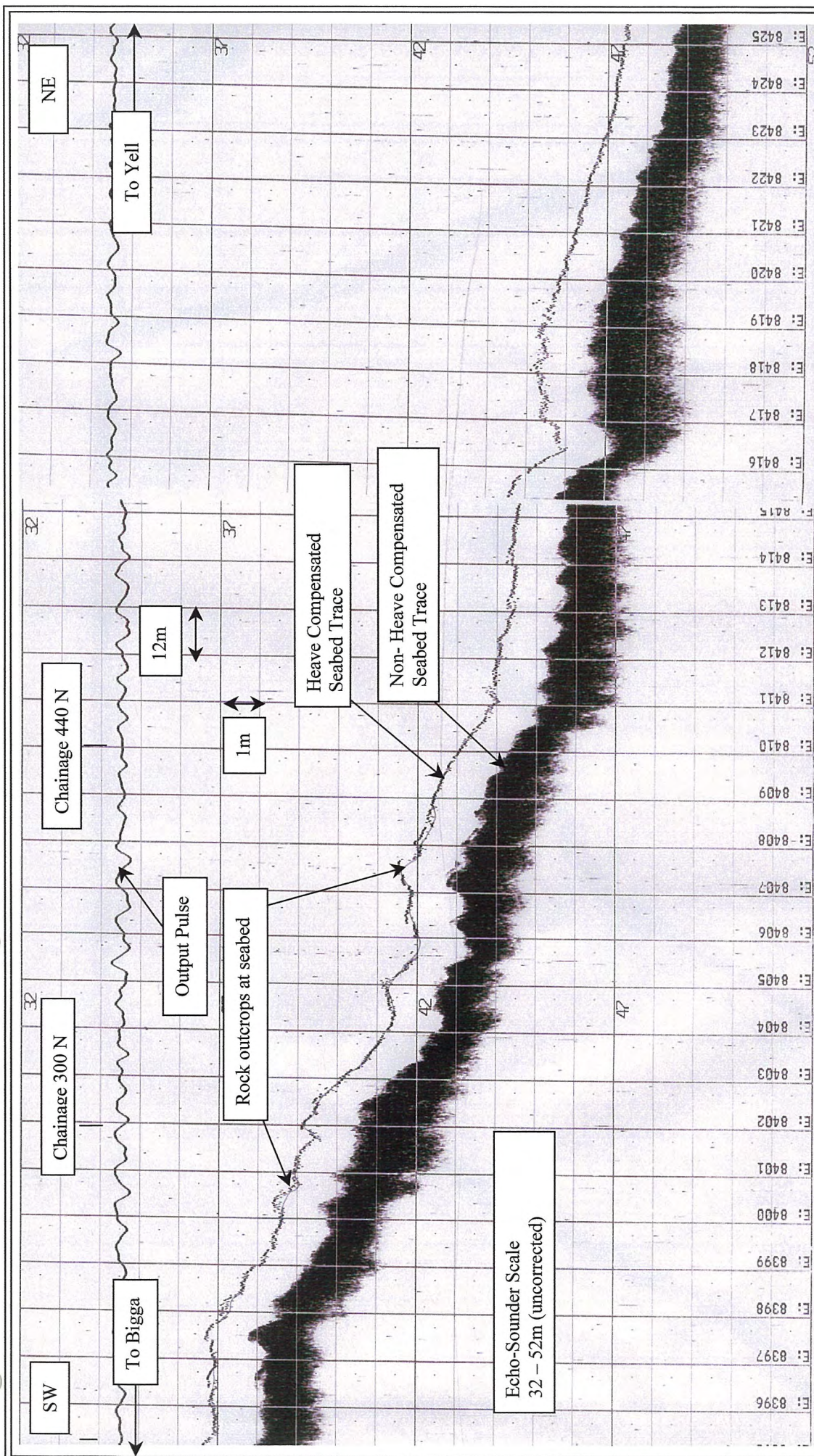


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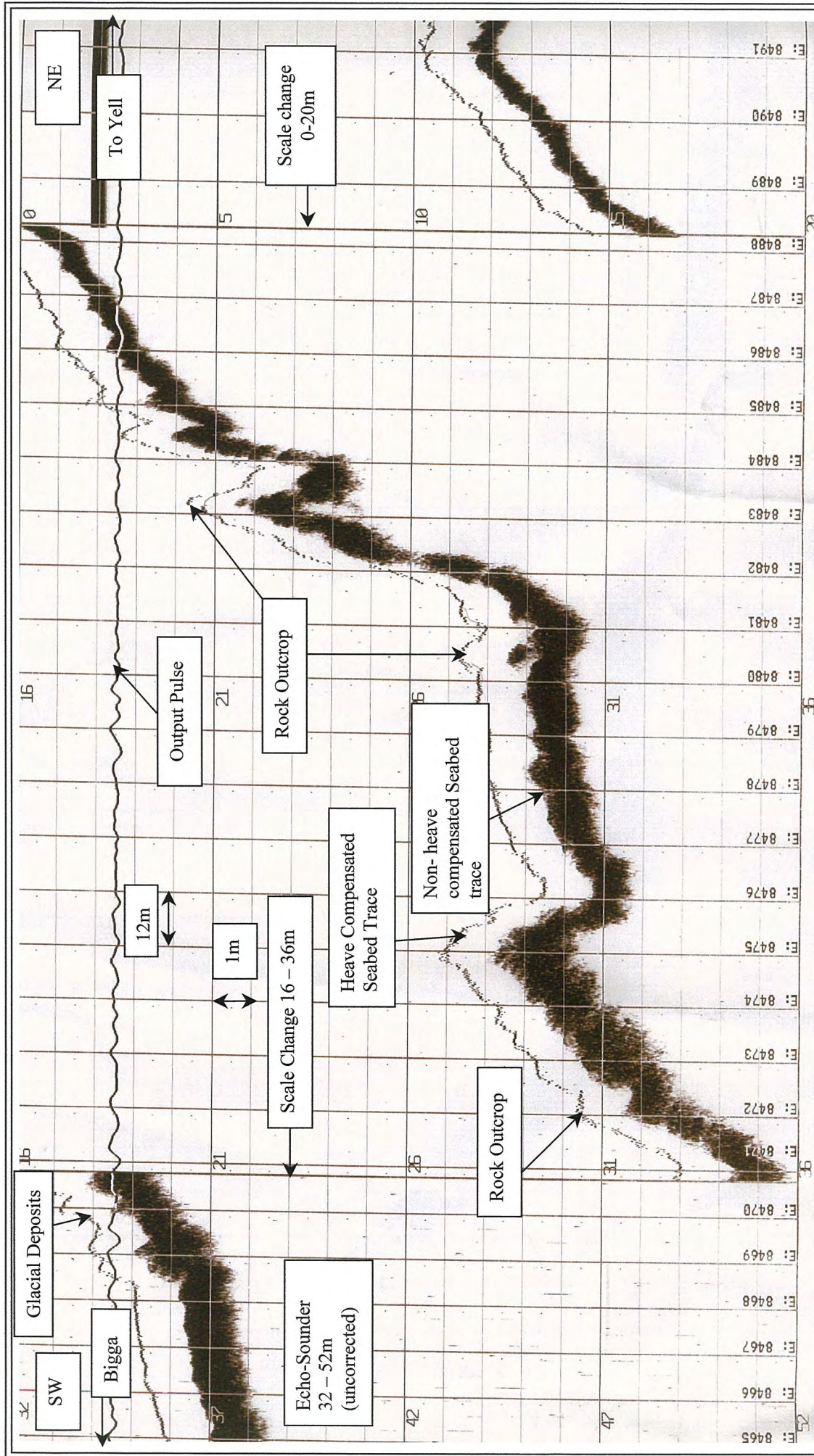


APPENDIX 3 DATA EXAMPLES



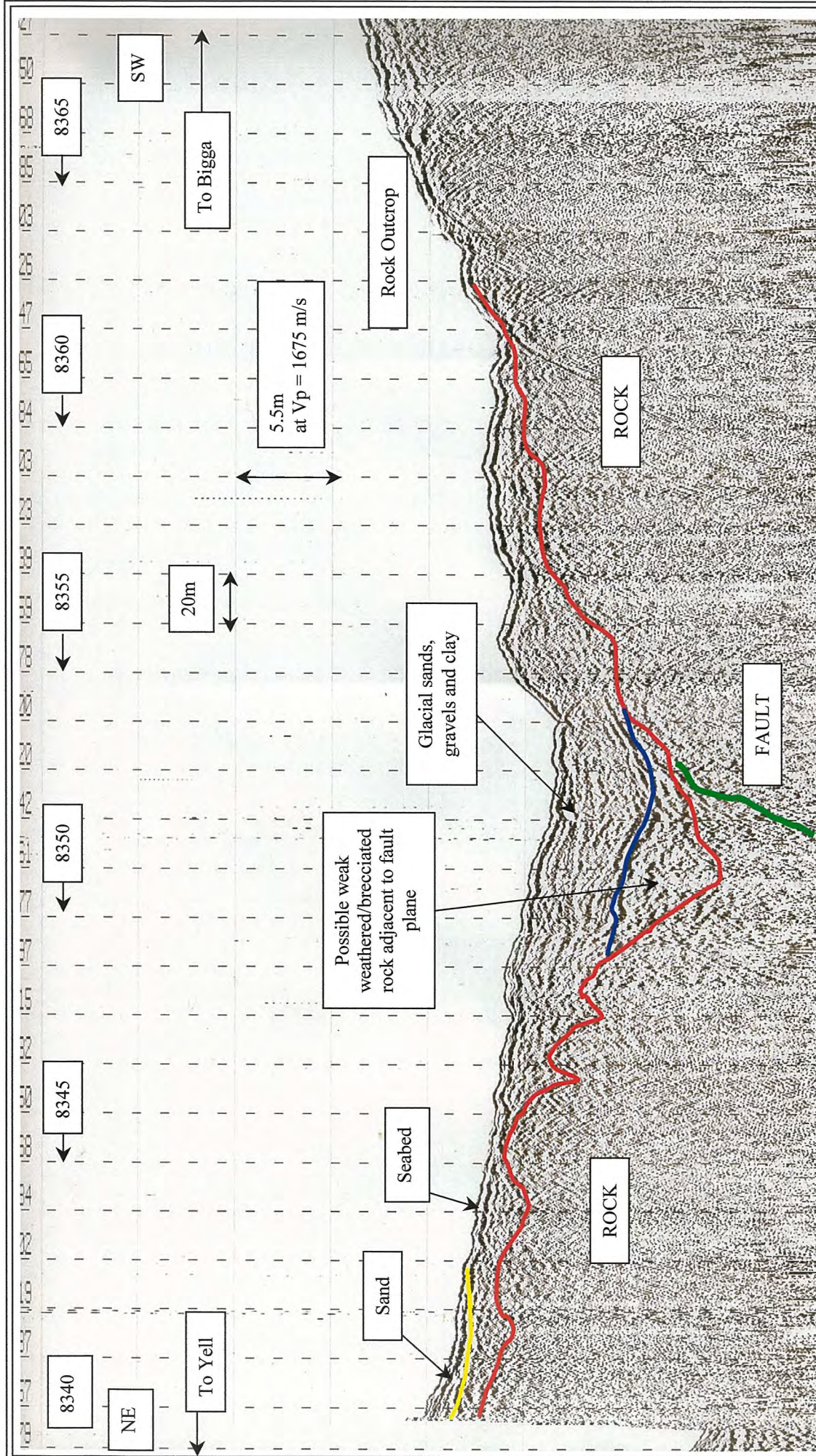
SHETLAND ISLANDS COUNCIL
Yell Sound
Geophysical Survey
Bigga to Yell

MM0209
Example of Echosounder Data
Fixes 8394 - 8425 close to North Tunnel Marine route, rock
outcrops extend to chainage 450m



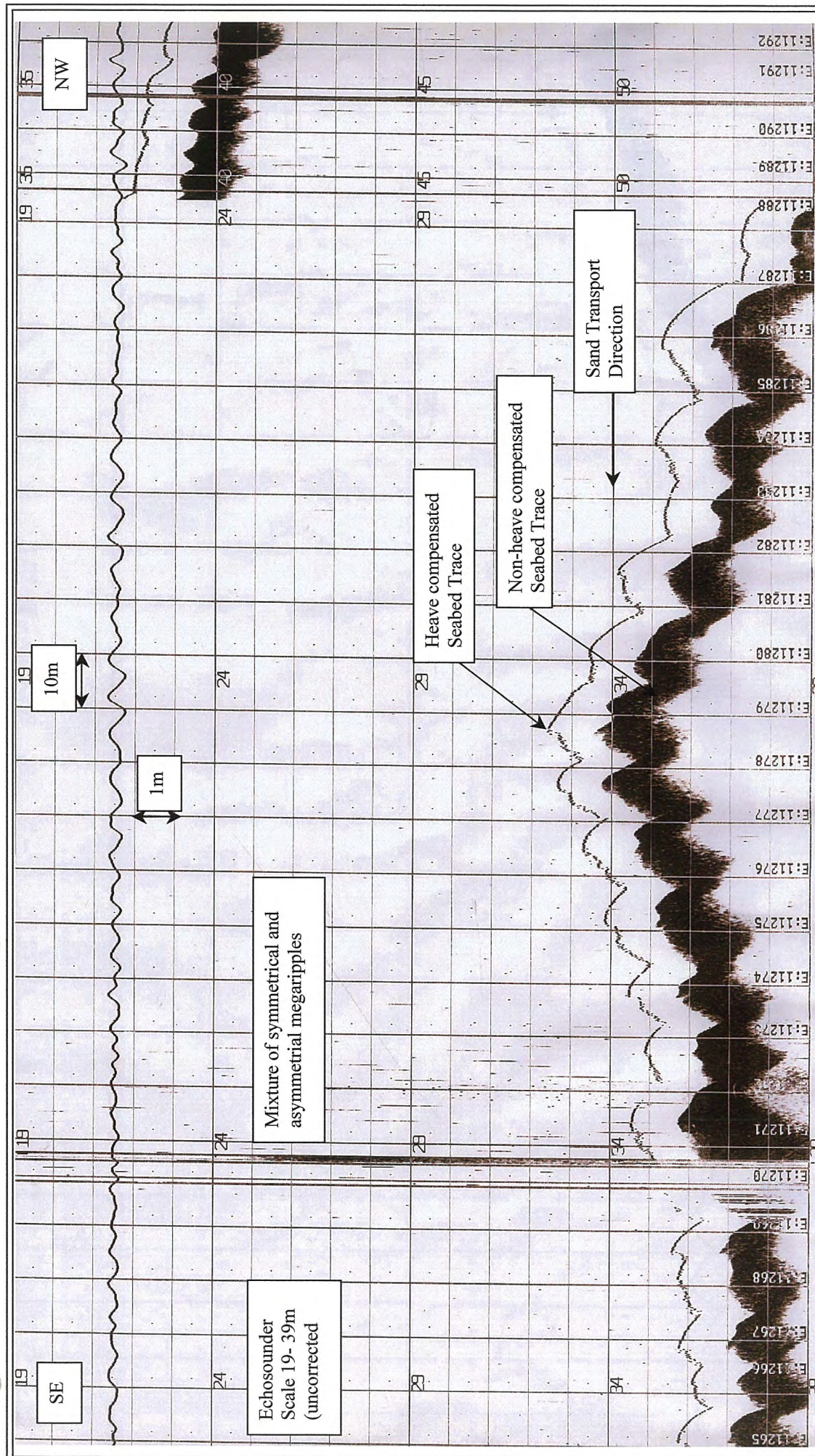
SHETLAND ISLANDS COUNCIL
Yell Sound
Geophysical Surveys
Bigga to Yell

MM0209
Example of Echosounder Data
Fixes 8465 - 8491 on section of route where North and South
options coincide on approaches to Yell



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Yell Sound
Geophysical Survey
Bigga to Yell

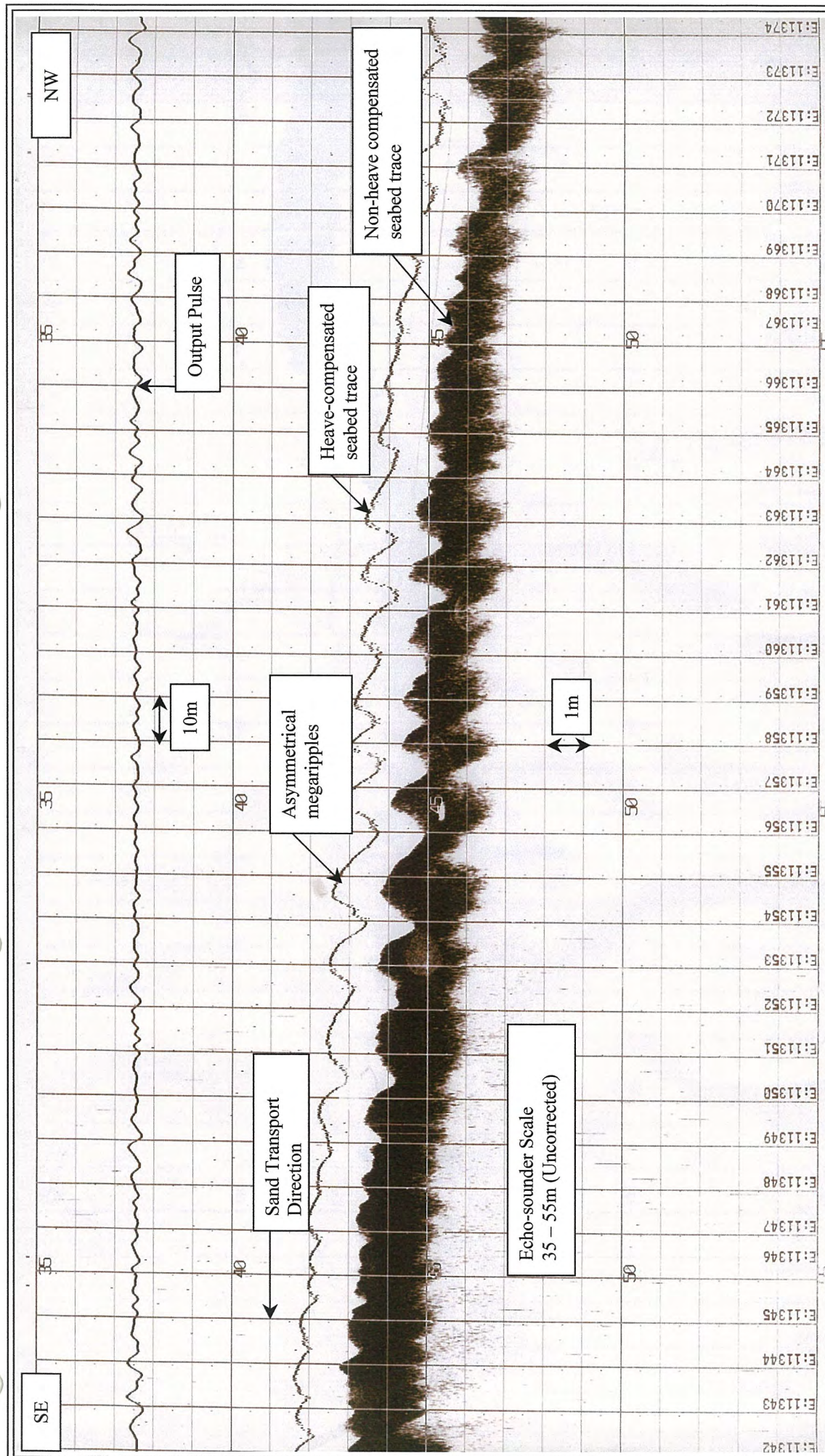
MM0209
Example of Boomer Data
Fixes 8340 – 8368 showing faulted section South of tunnel marine
route between Bigga & Yell



SHETLAND ISLANDS COUNCIL

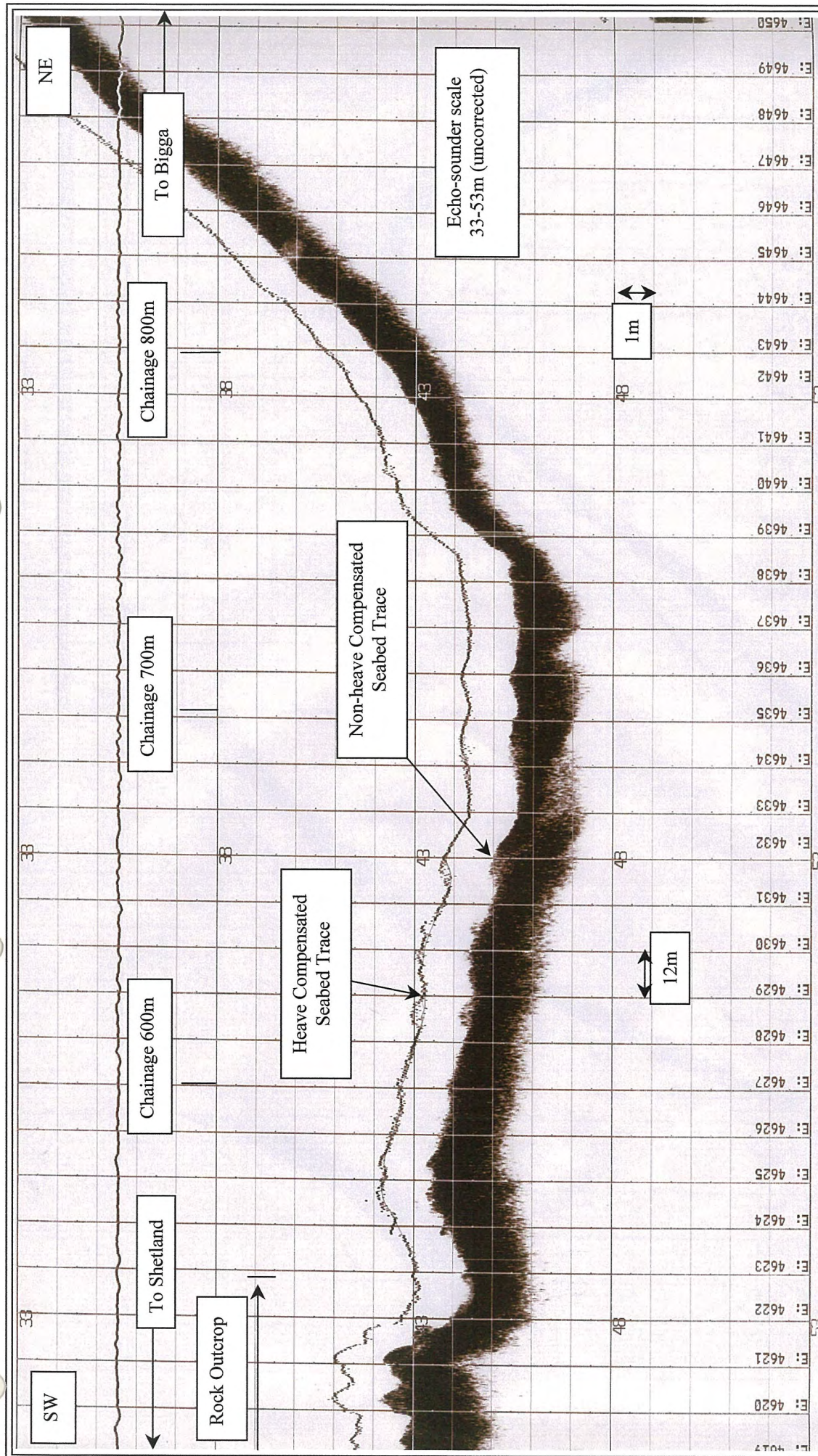
MM0209

Example of Echosounder Data
Fixes 11265 – 11292 showing asymmetrical megaripples over on
Sand Body 3 in south of survey area



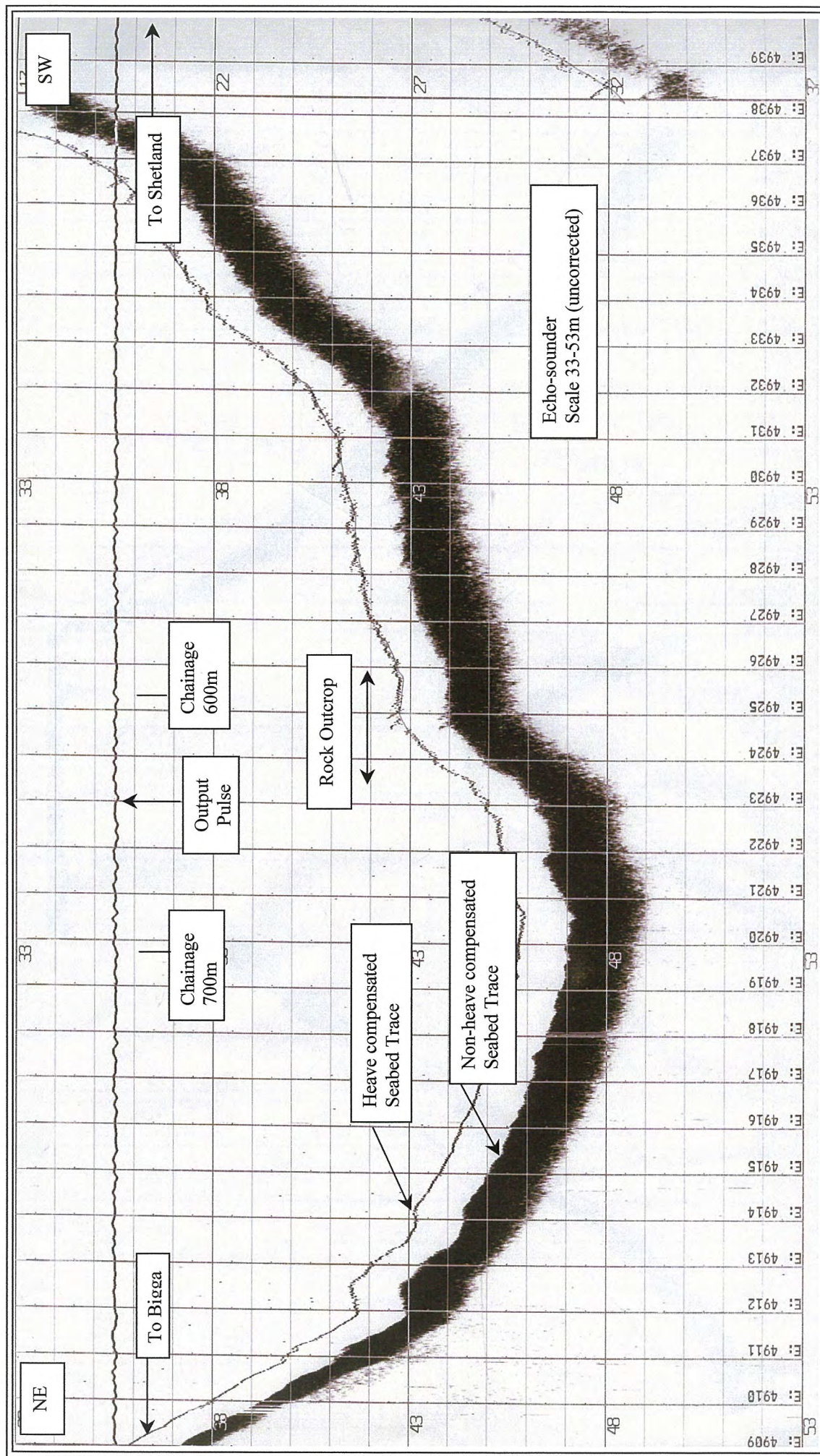
Shetland Islands Council
Yell Sound
Geophysical Survey
Bigga to Yell

MM0209
Example of Echosounder Data
Fixes 11342 – 11374 showing asymmetrical megaripples on Sand
Body 3 in north of survey area.



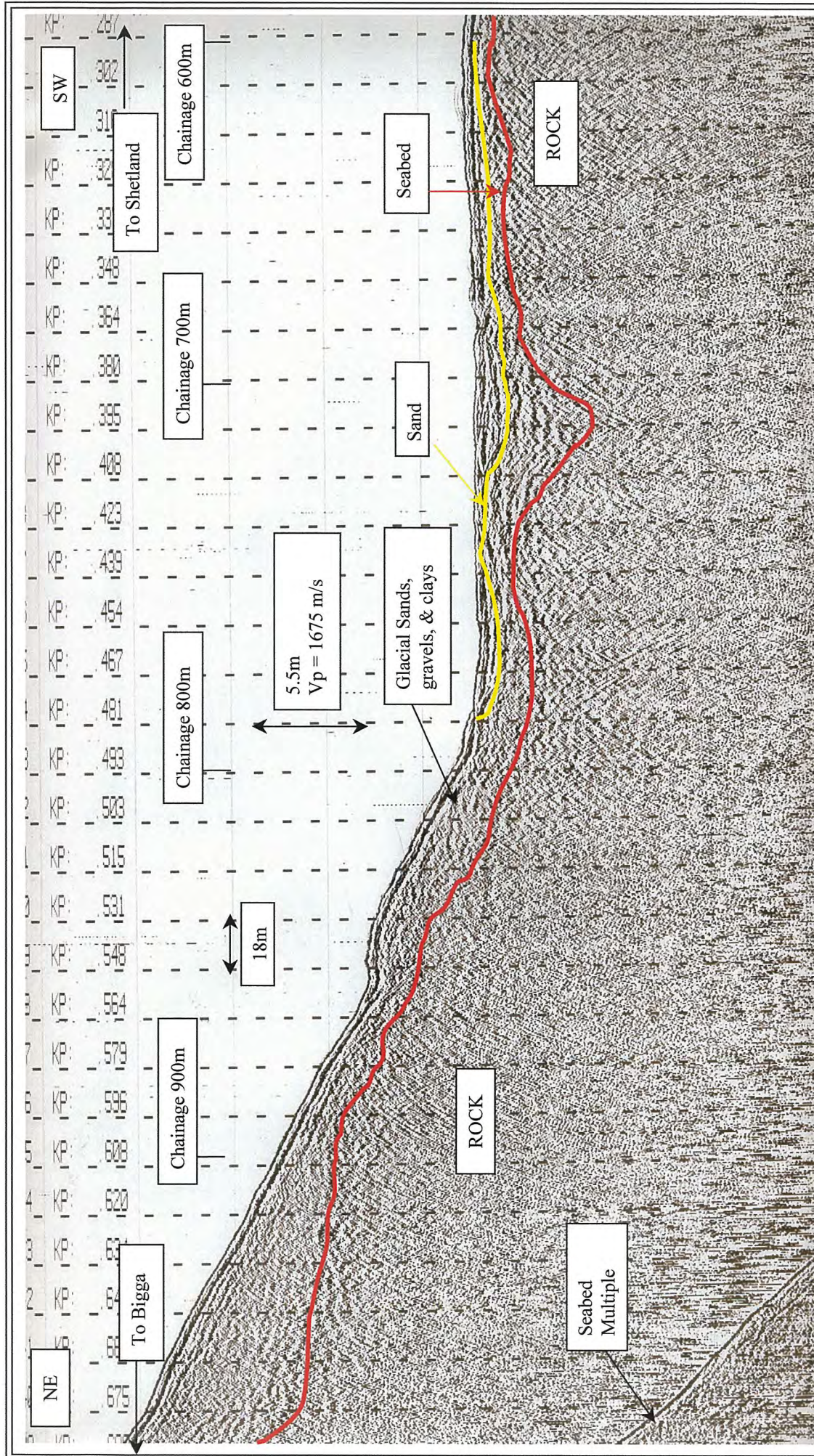
Shetland Islands Council
Yell Sound
Geophysical Survey
Shetland Mainland to Bigga

MM0209
Example of Echo-sounder Data
Fixes 4619 – 4649
Offset 15m North of South Tunnel Marine Route



SHETLAND ISLANDS COUNCIL
Yell Sound
Geophysical Survey
Shetland Mainland to Bigga

MM0209
Example of Echosounder Data
Fixes 4909 – 4938 close to North Tunnel Route



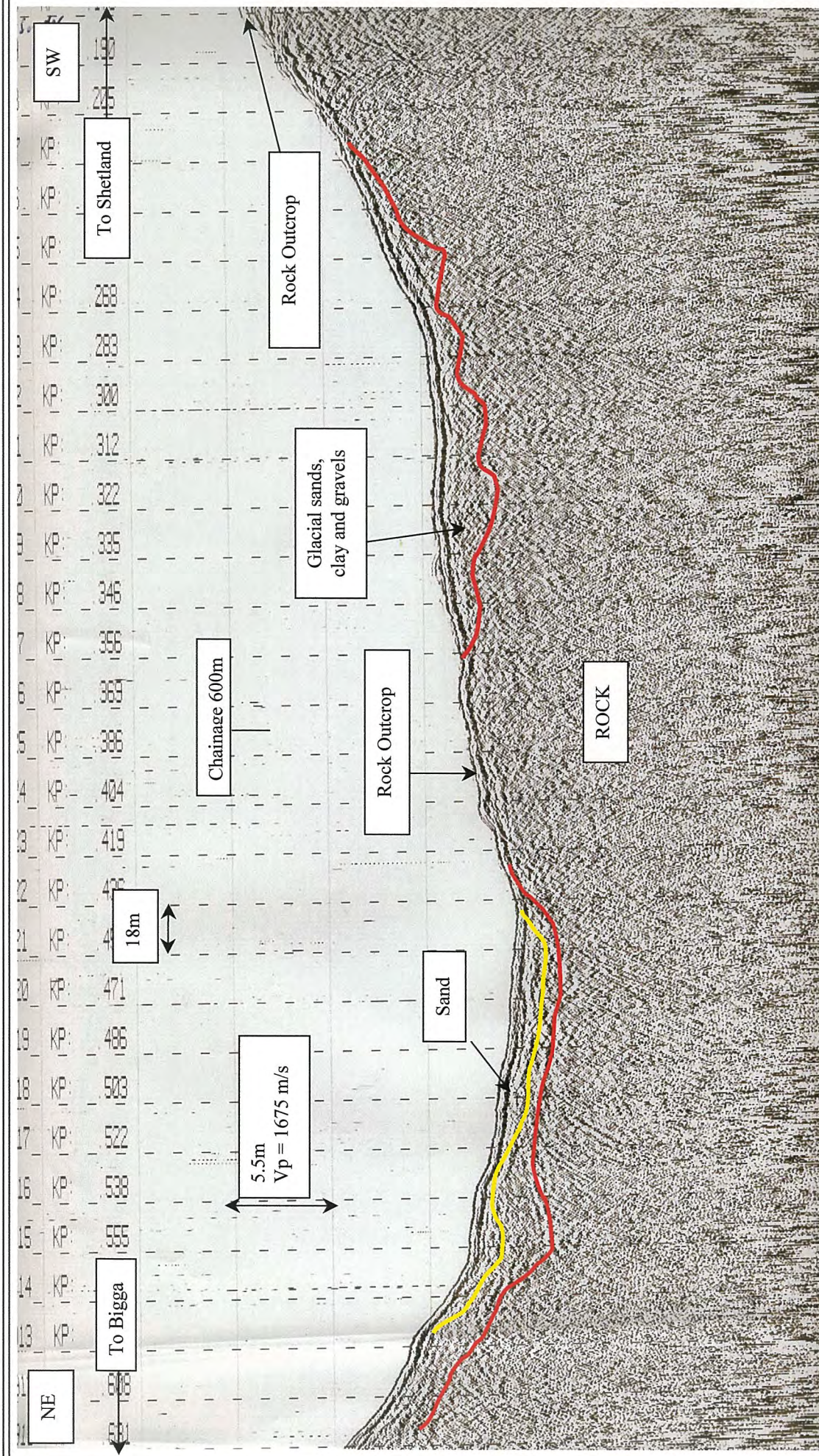
Shetland Islands Council
Yell Sound Geophysical Survey
Shetland Mainland to Bigga

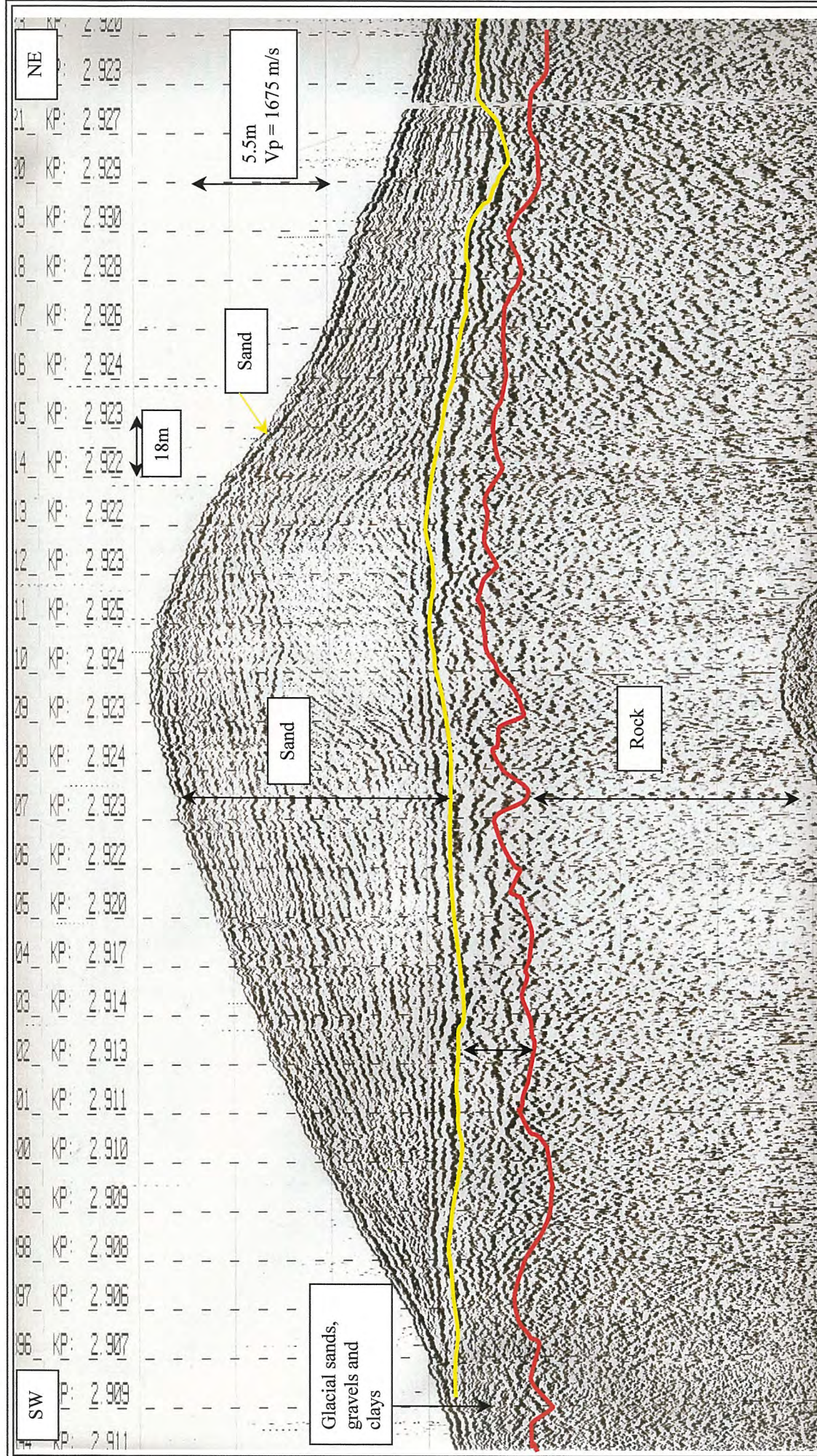
MM0209
Example of Boomer Data
Fixes 4539 – 4567 offset 25m
South of South tunnel marine route

MM0209

Example of Boomer Data

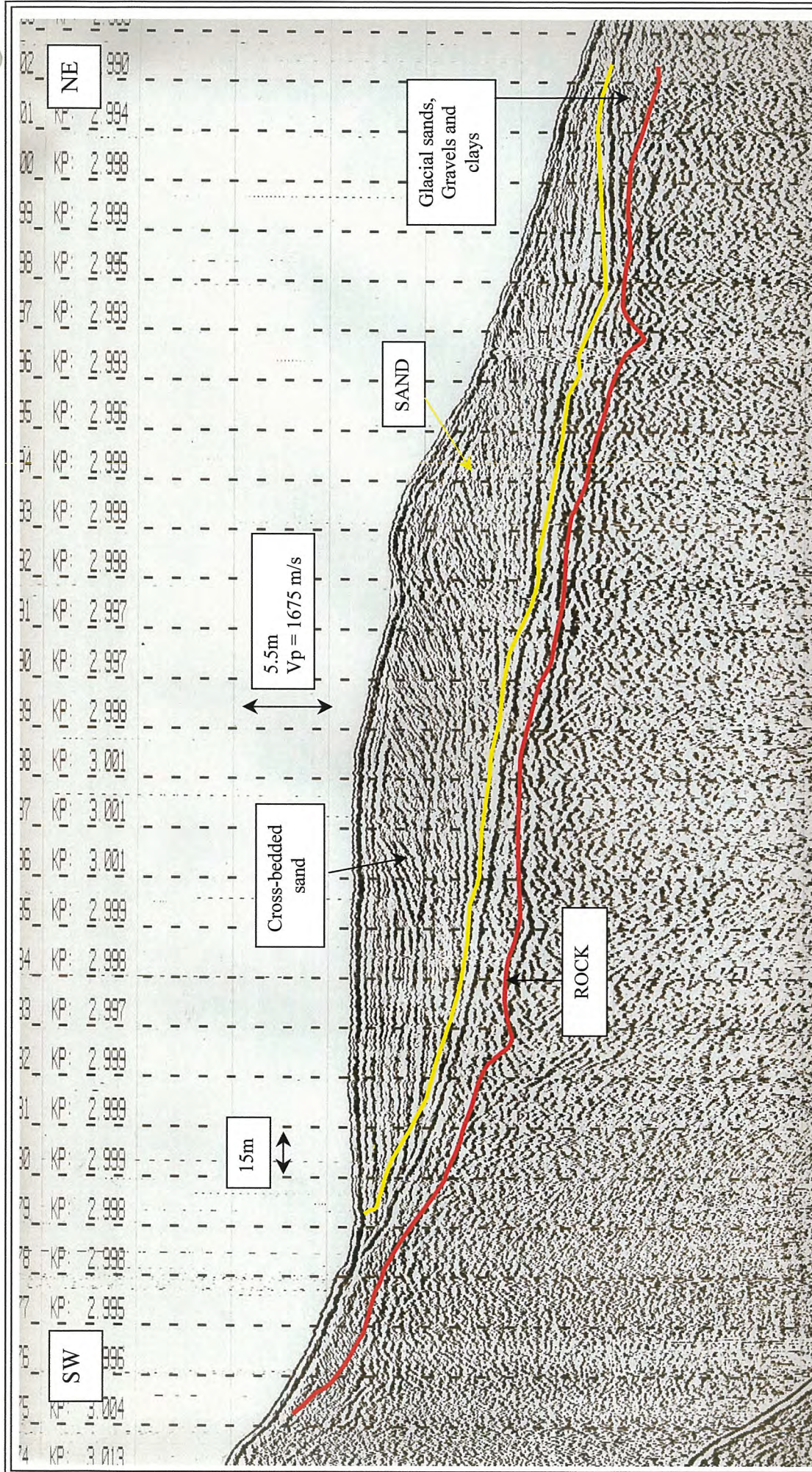
Fixes 4912 – 4946 close to North tunnel route at chainage 600m





Shetland Islands Council
Yell Sound Geophysical Survey
Shetland Mainland to Bigga

MM0209
Example of Boomer Data
Fixes 2394 – 2427
Sand Body 1 south of Bigga. The sand deposit is up to 16m thick.

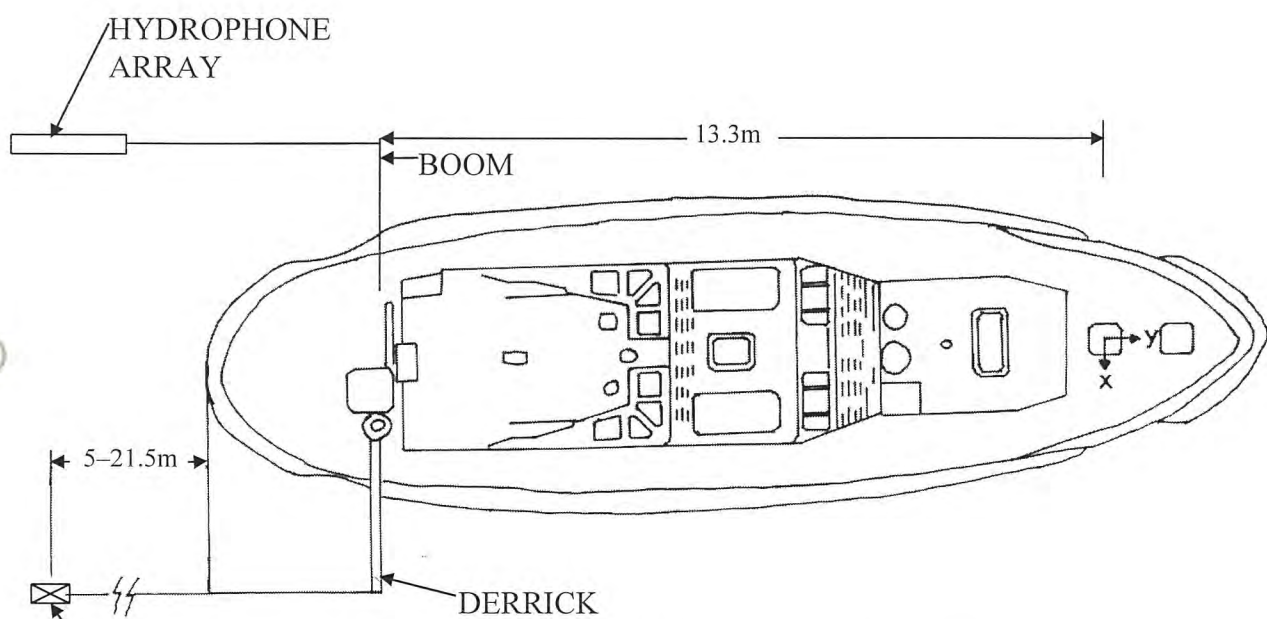
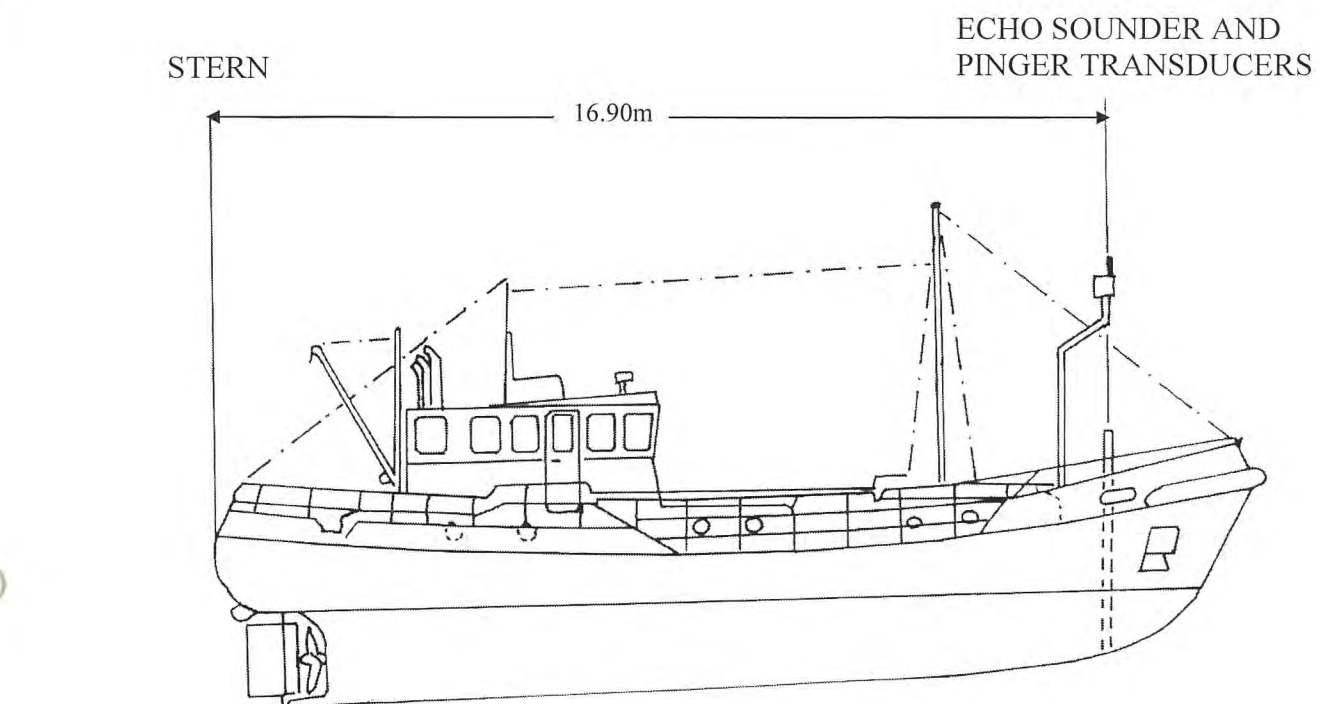


Shetland Islands Council
Yell Sound Geophysical Survey
Shetland Mainland to Bigga

MM0209
Example of Boomer Data
Fixes 2174 – 2206
over Sand Body 2



APPENDIX 4 VESSEL OFFSETS



Echo sounder and pinger transducer offset $x = 0$
 For z values, see moonpool drawing $y = 0$

Tow point for Boomer offset, from navigation antenna $x = +ve\ 3.5m$
 $y = -ve\ 13.3m$

R.S. DISCOVERY ROSE: SENSOR OFFSETS

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Title YELL SOUND TUNNEL PROJECT
Project No. MM0209



APPENDIX 5 GEOLOGICAL LOCALITIES & DESCRIPTIONS



BIGGA TO YELL
GEOLOGICAL LOCALITIES & DESCRIPTIONS
 (Ref : MM0209/E4)

Locality No.	Coordinates (E,N)	Description
1	445630,1180475	Shatter/shear belt in geo: This feature causes the rock to be easily eroded and weathered, and is a zone of weakness. Corresponds to the edge of sub-sea rock exposure indicated by geophysical survey and a zone of thickened sediment cover. Together with two intersecting joint sets, it is the cause of formation of the Feaddie Geo.
2	445650,1180330	Structures identified from shore photographs: Minor structures, possibly faults. These features are not deeply eroded and thus do not appear to represent zones of major weakness. They correspond to the edge of sub-sea bedrock exposure indicated by geophysical survey.
3	445710,1180230	Structure identified from sea-based photography: Forms a small embayment in the coastline and is possibly a fault zone.
4	445879,1179701	Fault zones: These two fault zones are eroded to form embayments in the coastline and along their seaward extension affect the morphology of sub-sea bedrock exposure.
5	445956,1179570	Fault zone: Fault identified via extension of geophysics-interpreted structure and sea-based photographs. On photographs, it occurs as a very slight indentation of the coastline and is not a site of major erosion. However, it significantly affects the morphology of sub-sea bedrock exposure.
6	446170, 1179486	Shatter/shear belt: This structure lies in a slight embayment in the coastline indicating that it is susceptible to erosion. However, it is not deeply eroded and therefore does not appear to be a zone of major weakness on surface. It corresponds to a fault identified by the geophysical survey that affects the morphology of sub-sea bedrock exposure and has led to a zone of increased sediment cover seaward.
7	444610,1179545	Shatter/shear belt: This structure is eroded into a deep gully, indicating that it is a zone of considerable weakness susceptible to erosion. Its orientation and position corresponds with a marked thickening of sediments seaward and a fault identified by the geophysical survey.
8	444650,1179472	Shatter/shear belt: This structure was identified on shore-based photographs. It takes the form of a deeply eroded gully and it is a zone of weakness. Its seaward extension corresponds to a significant indentation in the geophysics-interpreted line of bedrock outcrop and a geophysics-identified fault.
9	444875,1179092	Cave: This cave was identified on sea-based photographs. It is situated in a substantial embayment in the coastline and its planar southern side suggests that it may be a shatter/shear belt. The depth of erosion of this feature identifies it as a zone of weakness.



Locality No.	Coordinates (E,N)	Description
10	444883,1178954	Shatter/shear belt: This structure is deeply eroded to form an embayment in the coastline and is therefore a zone of weakness in the country rock. It was identified by geophysical survey, and can be traced a substantial distance into the eastern sound.
11	444932, 1178772	Shatter/shear belt: This structure is 6m wide and strongly eroded into a wide embayment in the coastline indicating that it is a zone of weakness. On shore, the orientation of foliation can be seen to change across this structure.
12	445022,1178696	Shear zone: This feature corresponds to a wide, open embayment in the coastline indicating that it is a zone of weakness. This structure does not appear to affect the morphology of the sub-sea bedrock surface identified by geophysical techniques.
13	4445062,1178554	Shatter/shear belt: This 2m wide zone is not significantly eroded. It is situated approximately 25m north of the central axis of a significant embayment into which a major fault identified by geophysical techniques intersects the coastline sub-parallel to the 2m wide shatter/shear belt identified above. It is thus likely that the fault identified on shore is not the major structure in this area and is associated with a more significant, sub-parallel structure coincident with the embayment axis and the geophysics-interpreted fault whose effects are evident on sub-sea bedrock morphology far from shore.
14	445055,1178424	Shatter/shear belt: Belt eroded into a relatively long, narrow gully identifying it as a zone of weakness. It is not evident in the geophysical interpretation of sub-sea bedrock morphology and may thus be limited in extent.
15	445025,1178404	Shatter/shear belt: This feature is eroded into a long, narrow gully which is offset along its length by later, discordant shearing. It is easily eroded and thus represents a zone of heightened weakness within the rock. It could not be traced seaward by geophysical techniques employed during this survey.
16	444985,1178367	Zone of shearing: This is a complex zone of intersecting shears resulting in substantial weakening of the rock. It possibly corresponds to an area of greater erosion and increased sediment cover seaward identified by geophysical survey. Shearing has disturbed foliation orientations in this area and at localities 14 and 15 above.



SHETLAND MAINLAND TO BIGGA GEOLOGICAL LOCALITIES & DESCRIPTIONS

(Ref : MM0209/W4)

Locality No.	Coordinates (E,N)	Description
17	444720,1178308	Shatter/shear belt: This belt shows no signs of preferential erosion and is thus probably not a major zone of weakness. It coincides with the edge of sub-sea bedrock exposure identified by geophysics.
18	444525,1178605	Structures identified from sea-based photography: These structures are relatively minor and occur sub-parallel to foliation trending across the channel axis between Bigga and Shetland Mainland. They are not significantly eroded and thus probably do not represent zones of major weakness.
19	444404,1178728	Shatter/shear belt: 2.5m wide shatter/shear belt. Sea-based photographs indicate that the coastal cliffs are lower in this general area than to the north and south, possibly indicating that this shear belt is associated with a zone of weakness in the rock. It corresponds to an area of increased sediment cover identified by geophysical techniques.
20	444320,1179200	Zone of shearing: Shear zone identified from shore-based photography. This shearing has resulted in weakening of the rock causing increased erosion into an embayment in the coastline. It corresponds to an area of increased sediment cover and depression in sub-sea bedrock identified by the geophysical survey. This zone marks a general change in cliff morphology from steeper and higher to the south to less steep and lower to the north.
21	443480,1178340	See 22
22	443590,1178200	Shear belt: This structure corresponds with a line of bedrock outcrop identified by the geophysical survey. North of this point, the rocks change character to more massive granites up to locality 21, whereafter they become foliated again.
23	443625,1178150	Shatter/shear belt: 2m wide zone resulting in a minor embayment of the coastline. The limited extent of erosion of this feature suggests that it is not a major zone of weakness. It does not affect the morphology of sub-sea bedrock as interpreted by geophysics.
24	443700,1178070	Shatter/shear belt: 2m wide zone showing little preferential erosion. The limited extent of erosion of this feature suggests that it is not a major zone of weakness. It does not affect the morphology of sub-sea bedrock as interpreted by geophysics.
25	443725,1177965	Shatter/shear belt: 6m wide structure eroded into a long, deep, steep-sided gully. This preferential erosion identifies this belt as a zone of weakness. It corresponds to the edge of sub-sea bedrock exposure as identified by geophysical techniques.



Locality No.	Coordinates (E,N)	Description
26	443740,1177860	Shatter/shear belt: This structure is not deeply eroded and is thus not a zone of major weakness. It does not affect the sub-sea bedrock morphology identified by geophysics, and was not identified by geophysical techniques. It may thus be a minor feature, quite limited in extent.
27	443840,1177495	Fault: Possible fault corresponding to embayment in coastline. Preferential erosion in this zone indicates that the rock is weak. It was not identified by geophysical survey, and may thus be limited in extent.
28	443940,1176790	Shatter/shear belt: Although forming a zone of weakness, the small degree of preferential erosion of this structure suggests that it is not a major one. It does not appear to affect sub-sea bedrock morphology as interpreted from geophysical information.

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APPENDIX 6 DRAWINGS