CALEDONIAN
GEOTECH

CONTENTS **PAGE NO**

APPENDICES

1.0 INTRODUCTION

Caledonian Geotech were contracted by Messrs Halcrow Crouch, Consulting Engineers, to conduct a geophysical and hydrographic survey over an area measuring 480m x 50m, lying between Shetland Mainland and Bressay Island. In order to obtain information in shallow water, an additional number of shore-parallel runs were carried out; an area measuring approximately 500m N-S by 300m W-E was actually surveyed. The purpose of the survey was to obtain topographic information on the seabed together with surface and subsurface sediment information, to assist in the selection of a route for a proposed bridge which would link Bressay to the mainland.

The survey objectives of the site investigation were:

- to establish, if possible, the bedrock profile and levels along the preferred line of the proposed bridge;
- to determine the seabed levels and to locate any irregular relief;
- to conduct a sidescan sonar search to locate any seabed hazards, debris or obstructions and to assist in identifying the seabed soils;
- to determine, if possible, the sequence of strata, extent and depth of subsoils, the nature of the soils and sediment layers, and to identify any boulders and obstructions within the overburden;
- to comment on any drilling operations which may be considered necessary, to elucidate the ground structure at the site.

This report provides details of the methods and equipment used, together with the survey results, conclusions drawn and recommendations which are considered to be appropriate. The geophysical and hydrographic surveys were carried out on 6th May 1999.

2.0 EQUIPMENT AND METHODS

2.1 SURVEY VESSEL

The acoustic survey was conducted from Caledonian Geotech'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 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 sub-bottom profiler positional data.

A 250kg derrick and winch, fitted at the stern of the vessel, was used to deploy the sparker on the starboard side of the vessel. The survey configuration of the geophysical equipment is illustrated in Appendix 3.0, Sensor offsets.

2.2 NAVIGATION

Vessel navigation was provided by a Navsymm XR6 Real Time Kinematic Differential Global Positioning System (RTK DGPS) comprising two, 12-channel receivers. The base station receiver was positioned over a survey station, 7(F), provided by the Client. (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 spacing for clarity.

The echo-sounder was operated continuously throughout the sub-bottom profiler and sparker surveys. Data was reduced using tidal information obtained from shore based tidal dippings and the tidal curve so derived is enclosed in Appendix 2.0.

2.4 SIDESCAN SONAR

The survey was carried out using a Klein 521, 100 kHz sidescan sonar system. The system comprises a graphic recorder, which is linked to a two channel 100kHz tow fish by a signal conducting towcable. Acoustic pulses are generated from the transducers mounted on each side of the tow fish; the tow fish transducers receive reflected acoustic energy and the information is then passed to the graphic recorder. This, in turn, provides a paper record of the seabed relief and texture along a corridor extending 75m each side of the vessel.

Two side scan survey lines were run at a distance apart of 150m and this ensured complete sonar coverage of the survey area. Layback corrections between the towfish and vessel antenna were calculated from a measured offset and the length of 'cable out' over the stern.

2.5 SUB-BOTTOM PROFILERS

Two systems were employed. The first, a high frequency (3kHz-7kHz) ORE 'Pinger' sub-bottom profiler system, provided high resolution information of the seabed sediments. The second, a lower frequency (0.5kHz-3kHz), Innerspace 'Sparker' system enabled greater sub-surface penetration, thereby providing information on the surfaces of more deeply buried strata. To optimise the signal to noise ratio, the hydrophone array was trailed 30m behind the vessel. Both systems were linked to an EPC 1086 thermal recorder for graphical display of the data.

2.6 SCOPE OF WORK

The original commission was to undertake three traverses parallel to the proposed route centre-line, the central traverse being sited along the route, with two further traverses being conducted along parallel lines 25m offset to each side of the route. A further 9 no traverses were required, orientated at right-angles to the bridge route, and each was to be 75m in length; the central 100m section of the route was not to be surveyed.

In the event, additional lines were run, as can be seen from the drawings, as it was felt a more comprehensive interpretation could be undertaken from a fuller picture of sub-seabed geometry. Sketch drawings of three profiles were specified.

For purposes of reference, the National Grid has been used for planimetric position and levels have been related to L.A.T. (Lowest Astronomical Tide), which is 1.22m below O.D. Lerwick, at the site.

Chainage has been referenced to station 'D' on the Bressay shore, as indicated on the Client supplied drawing. The shallow water depths which were available did limit the approach to the shore; in the case of the Bressay side, surveys extended to between 40 and 60m from the MLWS line, whilst on the Lerwick side, this distance was reduced to between 18 and 30m. Large boulders and exposed bedrock, on the seabed and in the shallow water, precluded closer approaches than this.

3.0 GEOLOGICAL BACKGROUND

The proposed bridge crossing is anticipated to traverse Bressay Sound from Annfield on Bressay Island to the Point of Scattland on Shetland Mainland. (Refer Halcrow & Crouch Drawing No: 99535-01 for the exact orientation.)

The country rocks which might be anticipated to lie below the bridge line area consist of Middle Old Red Sandstone, having dips varying between 20° to the SW - at the Point of Scattland where a suite of conglomerates are exposed, and approximately 15° to the SE on Bressay - where the rock types are non-conglomeratic sandstones. Between these two sites, with their varying dip directions, there is evidently either a structural discontinuity or simply a change due to folding of the strata.

The Old Red Sandstone of the Lerwick area forms discontinuous outcrops, which extend from Rova Head, 3.5km north of Lerwick, in a southward direction, for nearly 40km, to Sumburgh Head. The western offshore islands of Bressay and Noss are also composed principally of Middle Old Red Sandstone. The Old Red Sandstones can be divided into a number of sub-divisions, all based on slightly differing lithologies; these vary from breccias to conglomerates, sandstones and flags. The various facies are of limited lateral extent and tend to interdigitate with each other. All the sandstones have been deposited on an undulating basement of metamorphic rocks. Most were deposited sub-aerially, some as fan-glomerates and screes, bordering steep-sided and gullied hills. The broader valleys, into which the gullies and mountainsides drained, were floored with assemblages of sands, gravels and mud. Flash floods transported and deposited coarse, cobbly sediments; as the torrents subsided, so finer sediments – such as sands and silts, were laid down. The terrain was one of braided streams; the flooded river channel of one period not necessarily being occupied on the succeeding occasion of spate, when a different route would be adopted by the stream. The locations of the repositories for the sediments river cobbles and gravels can suddenly change, laterally, into sands, and back into gravels, as the channels of the ancient rivers are crossed. It is this mode of deposition, which results in "interdigitation" – literally interwoven fingers – of differing sediment sizes.

The cross-bedded Lerwick Sandstones thus contain, laterally and vertically discontinuous bands of cobbles and gravels, making them locally conglomeratic, and variations over short distances – in some cases but a few metres – will be present within the sequence.

The sequences are both folded and faulted, some of the latter of which is thought to reflect the complex geological structure of the metamorphic rocks, below. Of principal interest in this area are two sets of faults. One, which traverses the island of Bressay at a slightly east of north (west of south) direction, passes down through the Bressay Sound between Lerwick and Leira Ness. This structure undoubtedly controls, locally, the orientation of Bressay Sound. This is a major structure, and it may well be that the local change in the orientation of the sound, north of the Bay of Heogan is the consequence of the presence of a less pronounced, but associated, parallel structure, sited there.

A second faulting direction is one which is a 'splay' fault direction – a splinter – from the major coastal dislocation of the Nesting Fault, which runs the whole length of Shetland mainland, through Swining Voe in the north, to the west of Sumburgh in the south, passing en route along the western margin of Cliff Sound - the existence for which it is, undoubtedly, in part responsible. The major splay fault to the Nesting Fault has an arcuate outcrop, changing its orientation from N-S at a position 6km NE of Lerwick, to NW-SE near Brindister, 7km south of Lerwick. This secondary structure appears to be represented throughout the outcrops of Old Red Sandstone to the south and east of Lerwick, where its sub-parallel representatives control the margins of Gulber Wick, Voe Sound, Brei Wick, and, possibly the inlet between the Point of Scattland and Green Head within which the Bressay Bridge will be sited.

4.0 RESULTS

The results of the hydrographic and seismic surveys are presented in the following charts, which are contained in Appendix 5.0 of this report:

Drawing No.	Drawing Title	Scales
S9010/1	Bathymetry Chart	1:1000
S9010/2	Seabed Features	1:1000
S9010/3	Isopachyte of Unconsolidated Sediments above Rockhead	1:1000
S9010/4a-4b	Interpreted Geological Sections	1:1000H 1:100V

4.1 BATHYMETRY & SEABED FEATURES

Refer to Drawing No S9010/1 for soundings and contoured seabed at 1m intervals.

Refer to Drawing No S9010/2 for seabed features observed from the side scan survey.

Water depths along the bridge route reach a maximum of 6.9m or thereby below Chart Datum. The central channel is a dredged channel maintained below 6m over a width of 100m. The prevailing gradient is about 1:28 on the eastern Bressay side and 1:18 on the steeper approach to Shetland Mainland.

Elsewhere within the survey area, water depths reach a maximum of 8.5m below Chart Datum towards the north.

The sonar investigation found two possible debris contacts, located approximately 170m north of the bridge route. The seafloor is composed of a uniform, featureless sand to the northeast of the survey area and this develops laterally into an area of sandripples or megaripples, which are confined to the northwest of the survey area only. Towards the south, the grain size of the sands appears to become coarser, and gravels and sporadic areas containing low relief, occasional boulders and areas of rock outcrop, are apparent on both flanks of the channel. The central, dredged area appears to be rock free, possibly due to transport and deposition of mobile sands over the rock-cut dredged channel.

Below the bridge route, the seafloor is mainly very coarse sands and gravels - in the central dredged channel section - but rocks, albeit interspersed with occasional thin sandy patches, appear to compose both flanks of the channel and extend to the shore where the Old Red Sandstones are exposed.

Although the Admiralty Chart for the area shows a cable located to the south of the proposed bridge route, this could not be seen on the sidescan data.

4.2 SEISMIC PROFILING

The information from 'pinger' and 'sparker' surveys has been combined to provide a unified interpretation of the sub-seabed geology of the Bressay Bridge site. 'Pinger' records provide high resolution information about the superficial deposits in the range 0-8m, whilst 'sparker' records, although providing lower resolution, do provide superior sub-seabed penetration. An assumed acoustic velocity of 1675m/s has been used for the interpretation of the seismic data at this site and it is considered that this assumption is likely to quite appropriate for the upper materials above rockhead.

The geophysical survey results have made it possible to chart the thickness of overburden which has been classified, subject to borehole correlation, as a medium to coarse-grained SAND. This unit, on the evidence of the seismic survey, is believed to directly overlie an irregularly bedded, possibly fractured and heavily weathered unit of Old Red Sandstone which grades vertically within a few metres, into a more regularly bedded unit of possibly fresher or less weathered sandstones. It is equally possible that a layer of glacial boulder clay deposits may, in reality, cover the surface here interpreted as 'top' of bedrock. Because of the lack of acoustic impedance contrast between boulder clays and weathered or broken rock (e.g. boulders), it is not usually possible to differentiate between the two possibilities without reliable borehole control.

Drawing No. S9010/3 presents the thickness of the upper, unconsolidated sediments, which are likely to comprise sands, above the top of inferred rockhead.

Finally, Drawing No. S9010/4a-4b depicts three interpreted geological profiles: the preferred bridge line, and two alternatives, at 25m north and 25m south of the preferred route.

A selection of data examples collected at the site is presented in Appendix 4.0.

4.2.1 SEDIMENTARY OVERBURDEN

The seismic records enabled the identification of two sedimentary units overlying the rockhead level, which display the following seismic characteristics:

- **SAND**

  The Upper sand unit consists of an acoustically near-transparent unit with faint sub-parallel, planar bedding; this unit does contain occasional internal diffractions from coarser components. Although there is no direct sampling evidence, the upper sediments are likely to comprise loose marine sands. The sand deposit along the preferred bridge line varies from a minimum of 0.5m to a maximum of 2.0m, and this is in fair agreement to both the other two alternative routes.

The sand cover is confined to the central dredged channel, with occasional thin patches interspersed between rock outcrops - and a deeper gulley, shown on the drawings, on the Bressay side of the crossing. On the echo-sounder records, areas of mobile sand can be distinguished from areas of less mobile, hard substrate because of the absence of marine seaweeds such as Poseidonia or Laminaria which require an anchorage such as that provided by boulders or bedrock to which they might attach. The weed areas show up clearly in the water column of the echo-sounder and the hard substrate shows good correlation with the geophysical results.

4.2.2 ROCKHEAD LEVEL

In this area, rockhead level is interpreted to outcrop or subcrop over both flanks of the bridge route. In reality, a very thin veneer of superficial sediments probably overlies most of the outcrop areas which accounts for the appearance on the sidescan sonar data which shows 'patchy', low-lying areas of high sonar reflectivity interspersed by featureless infill sediments.

In the central, dredged area, infill sediments are clearly seen overlying dense material - which is interpreted as being the weathered and/or possibly fractured rock formation. In areas where rock outcrops at the seabed the seismic signature displays a dense acoustic character with numerous chaotic diffractions emanating from several point sources. Whether the first dense materials encountered are a thin layer of Boulder Clay deposits (or winnowed remnants thereof), or weathered Old Red Sandstone, can not be ascertained from the geophysical records.

The Old Red Sandstone, when it becomes weathered, frequently suffers mineralogical change to the feldspars which are present; these weather to clay minerals, resulting in a localised reduction in the strength of the cemented rock. Where this is incipient only, especially along joint surfaces, a separation of the intact rocks along the intersecting joints can occur, resulting in the formation of an assemblage of blocks of rock which are separated by clay-filled joints. In extreme cases, advanced degradation results in residual, gritty kernels of remnant rock within a clayey soil. It should be

Bressay Bridge S9010

Bressay Bridge – Photograph of landfall taken from nearest approach to landfall which the presence of large boulders on the seabed and water depths would allow appreciated that the geophysical data cannot differentiate between jointed, hard rock and weathered derivatives.

The strength of the seabed multiple on the seismic data tends to obscure deeper data by overprinting. This is a particular problem in shallow water surveys or areas with a hard seabed, which gives high amplitude reflected signals, which overprint deeper information.

Below the bridge line there is a thickness of 1.0m or less of overburden, which is mainly confined to the dredged channel.

As noted earlier, the upper strata appear highly irregular and fractured. In part this may be due to dredging operations in the maintained channel. Even in the flank areas, internal rock structure is difficult to elucidate, owing to the presence of many diffractions. A few metres below seabed a structure can be seen within the rock fabric which may be folding – or more likely faulting - and this would explain the differences in the dip directions observed between Shetland Mainland and Bressay. This structure crosses both the preferred bridge line and the alternative routes (see Geological Background).

It should be stressed that should the rockhead level be weathered, then fresh, unweathered rock will be located at a slightly deeper level. Borehole correlation would be advisable as a means of checking the mechanical condition of the rock and for correlation with the seismic data.

On the Bressay side of the crossing, large boulders – or slabs of rock – were seen exposed on the seabed, with intervening hollows being infilled by sand.

Bressay Bridge S9010

Bressay Bridge – Old Red Sandstone coarse conglomerate exposed on Mainland landfall dipping approx 40°

The photographs taken of the Bressay foreshore do indicate that detached slabs of rock are present there; it is probable that the boulders on the seabed and the upper horizons of the surface interpreted as bedrock are of similar character.

The possibilities of the constituents of the dense 'materials' which may lie at shallow depth beneath the seabed, have been discussed. Whilst the known history of dredging does confuse the drawing of conclusions from the association between the seabed topography and the material which it might comprise (which, in undisturbed sites, can be a very telling relationship) – it is nevertheless possible to draw some tentative conclusions. Comparison between the seabed, the bathymetry and the isopachyte charts (drgs. S9010/1 and S9010/2) does reveal some relationship between the two. It is immediately apparent that in the north-west of the area, where 'bedrock' is interpreted as being buried to a greater depth beneath the seabed (and below any dredging level), there is a marked embayment on the bathymetry chart. On the line of the bridge, on the margins of the dredged channel, the seabed contours form a small, but very evident salient, into the channel. Here, 'bedrock' – as interpreted – is interpreted as being at the seabed surface. At the western landfall for the bridge, conglomerate was seen exposed at the seabed, whilst immediately to the north, the interpreted bedrock surface becomes progressively buried. It is the case that where 'bedrock' is interpreted as being at the seabed surface a positive relief prevails, whilst where it is considered to be buried, embayments are sited. It follows that, whatever the reflector does represent, it is dense or hard. Whilst some similarity in topographical control might be expected from glacial till, the winnowing of the fine constituents, by the not insignificant currents which are present at this site would, in time, have the effect of 'levelling' the site, leaving the coarser constituents as a remnant pavement. Whilst, to some degree, this has almost certainly happened – for instance on the Bressay site, where large boulders were evident on the seabed - there remains a strong association between relief and the interpretation of the reflectors seen – which, on balance, assists in the drawing of the conclusion that this material is, indeed, bedrock.

5.0 SUMMARY

The route of the preferred bridge would appear to be floored by a dense material – interpreted as being the outcropping (or just subcropping) of Old Red Sandstone. The central dredge channel appears to contain a thin cover of infill sands, which are probably post-excavational deposits. Other patches of sands are developed in rock outcrop areas. The seafloor is mainly very regular and there are generally no areas of undue or sharp relief as would be caused be massive, irregular masses of rock, though the margins of the maintained channel are very evident. The low relief is believed to be due to a combination of the gentle dip of the O.R.S. together with some draping by a thin veneer of sediments which are too thin to quantify on the seismic records, (although they are definitely present, having been seen on the side scan sonar data).

6.0 CONCLUSIONS

1. Water depths below the bridge line reach a maximum of 6.9m below Chart Datum within a central dredged channel. The prevailing gradient is approximately 1:28 towards the channel axis from Bressay and about 1:18, from Shetland Mainland.

2. The overburden materials consist of an upper, very thin, coarse sand and gravel unit, which varies in thickness from 0.0 to 1.2m along the preferred bridge line.

3. The dense material, represented by the high amplitude, multi-diffracted reflectors on the seismic records, is interpreted as being bedrock. Whilst the possibility remains that this material is glacial till, this is considered, for a variety of reasons, to be the less likely option. Whatever the material represented by the reflectors seen is, it is harder and more compacted than the materials above; it forms areas of positive topographic relief on the seabed where exposed, and low lying sections of the seabed coincide with its absence. Weed adheres to the material, confirming its capability of providing a secure 'hold-fast'. Its surface is strewn with large boulders. The material forms flanking outcrops, on either side of the route, with only the central area being free of rock.

4. Rock quality is an unknown quantity, which can only be clarified by borehole investigation, though conglomerate was identified in outcrop on the mainland side of the crossing.

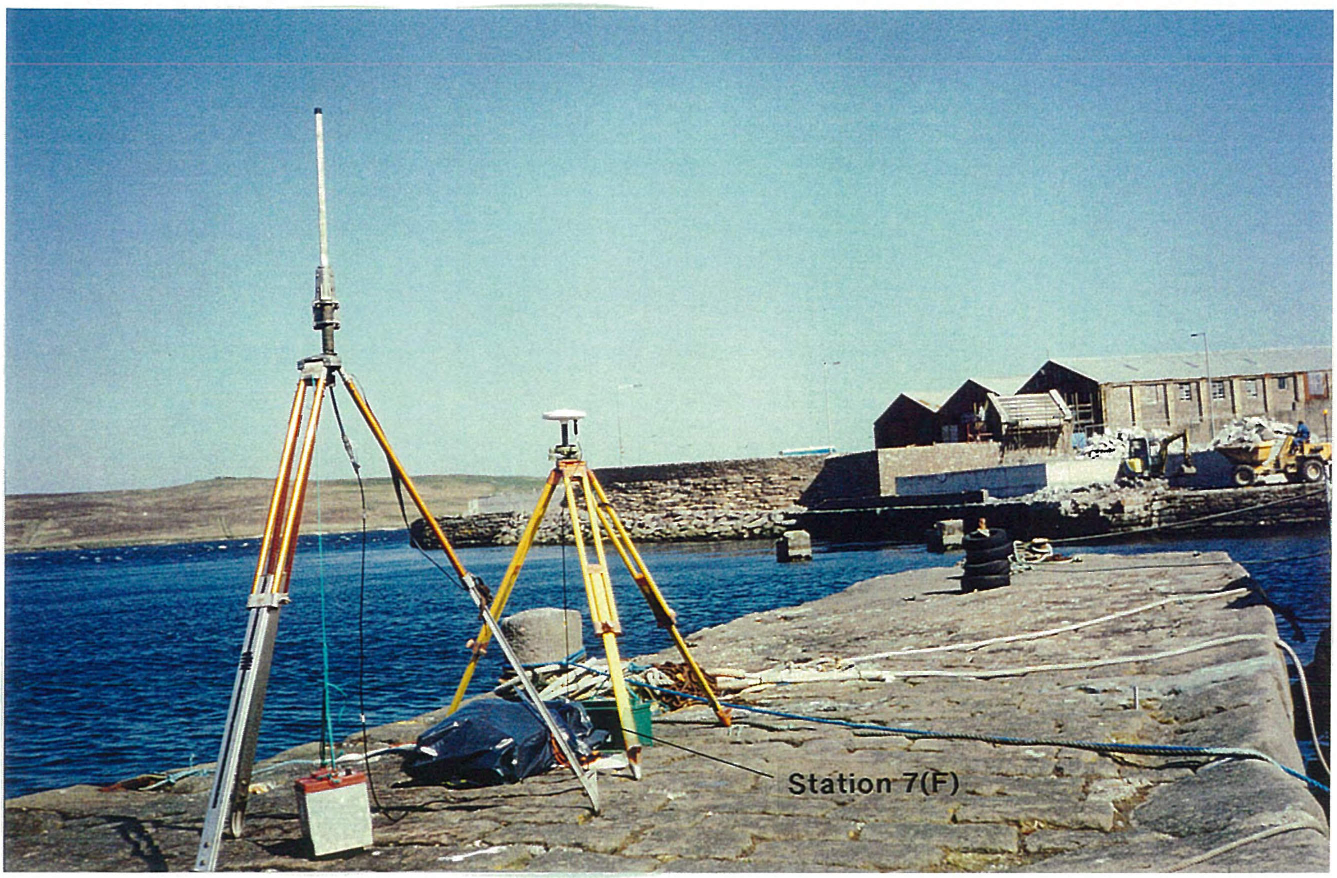
7.0 RECOMMENDATIONS

Prior to going to design stage, it is recommended that a borehole investigation be implemented to confirm the nature of the dense material interpreted as bedrock, and to obtain samples of the materials for strength and load-bearing testing purposes.

APPENDIX 1.0
SURVEY STATION DESCRIPTIONS

SURVEY STATION INFORMATION

Station Name: 7 (F)
Area/Location: Lerwick, Shetland Islands
O.S. 1:50 000 Sheet No: 4

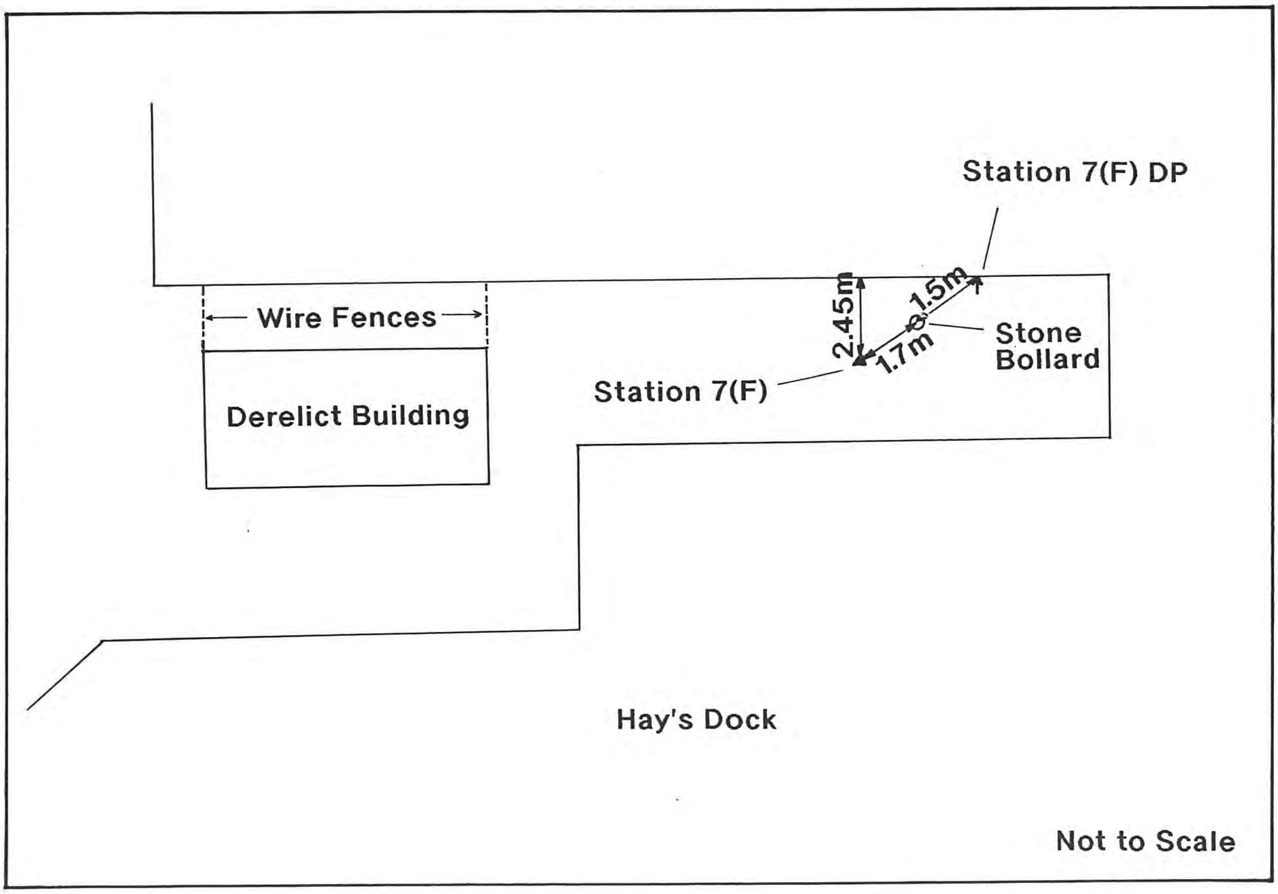


SURVEY STATION INFORMATION

Station Name:	7 (F)
Area/Location:	Lerwick, Shetland Islands O.S. 1:50 000 Sheet No: 4
Description of mark:	Rusty nail and washer painted yellow
Location of station:	The station is located on a narrow quay adjacent to Hay's Dock
Date of survey:	Unknown
Surveyed by:	Arch Henderson
Method:	Unknown
Accuracy:	Unknown
Comments:	The gates of the compound are locked at 17:00

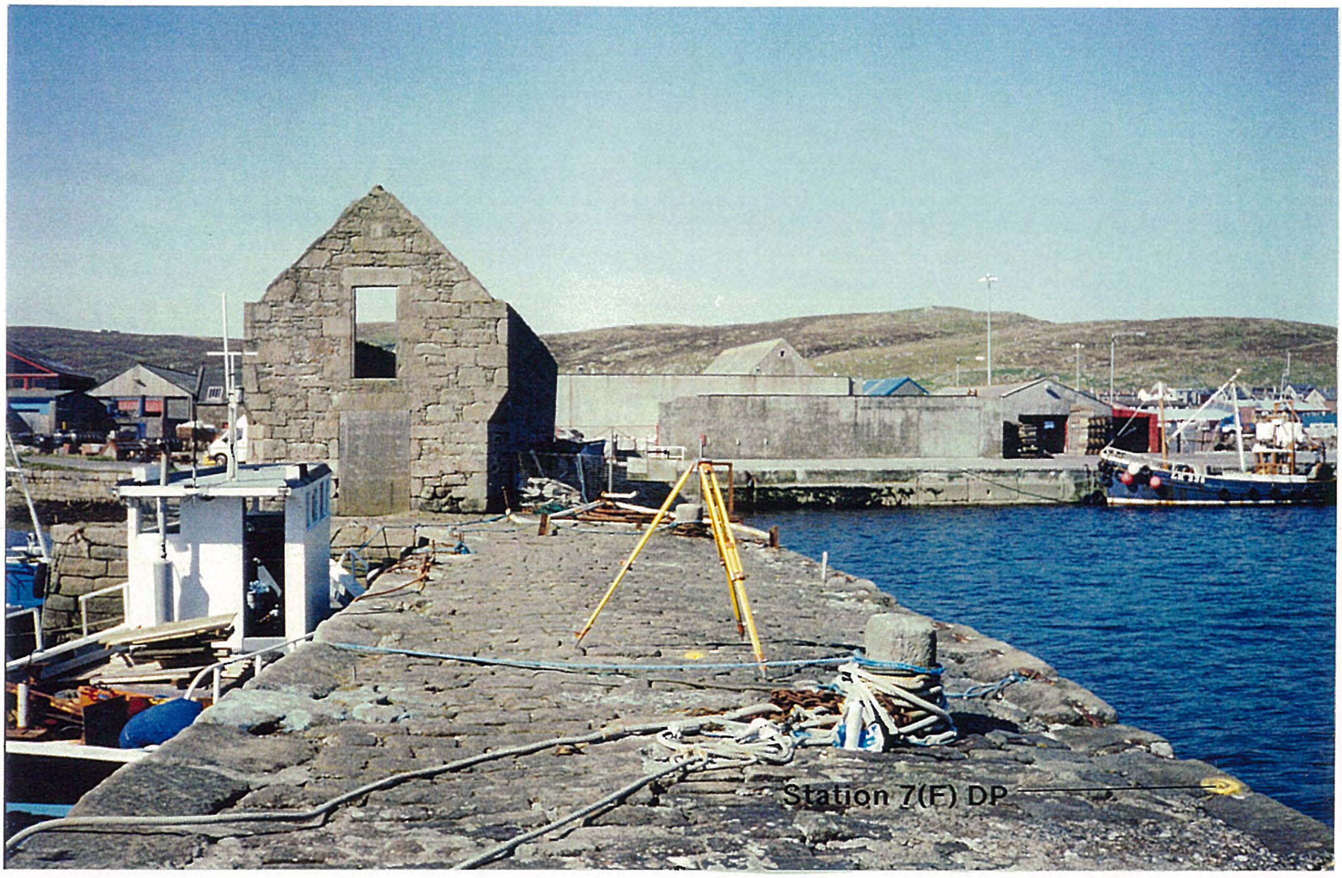
Co-ordinate Information:

Spheroid:	Airy	
Vertical Datum:	O.D. Lerwick	
Projection:	OSGB36	
Co-ordinates:	447312.41 E	LAT 60° 09' 32.650" N
	1141866.26 N	LONG 01° 08' 51.266" W
Elevation:	1.547m O.D.	



SURVEY STATION INFORMATION

Station Name: 7 (F) DP
Area/Location: Lerwick, Shetland Islands
O.S. 1:50 000 Sheet No: 4

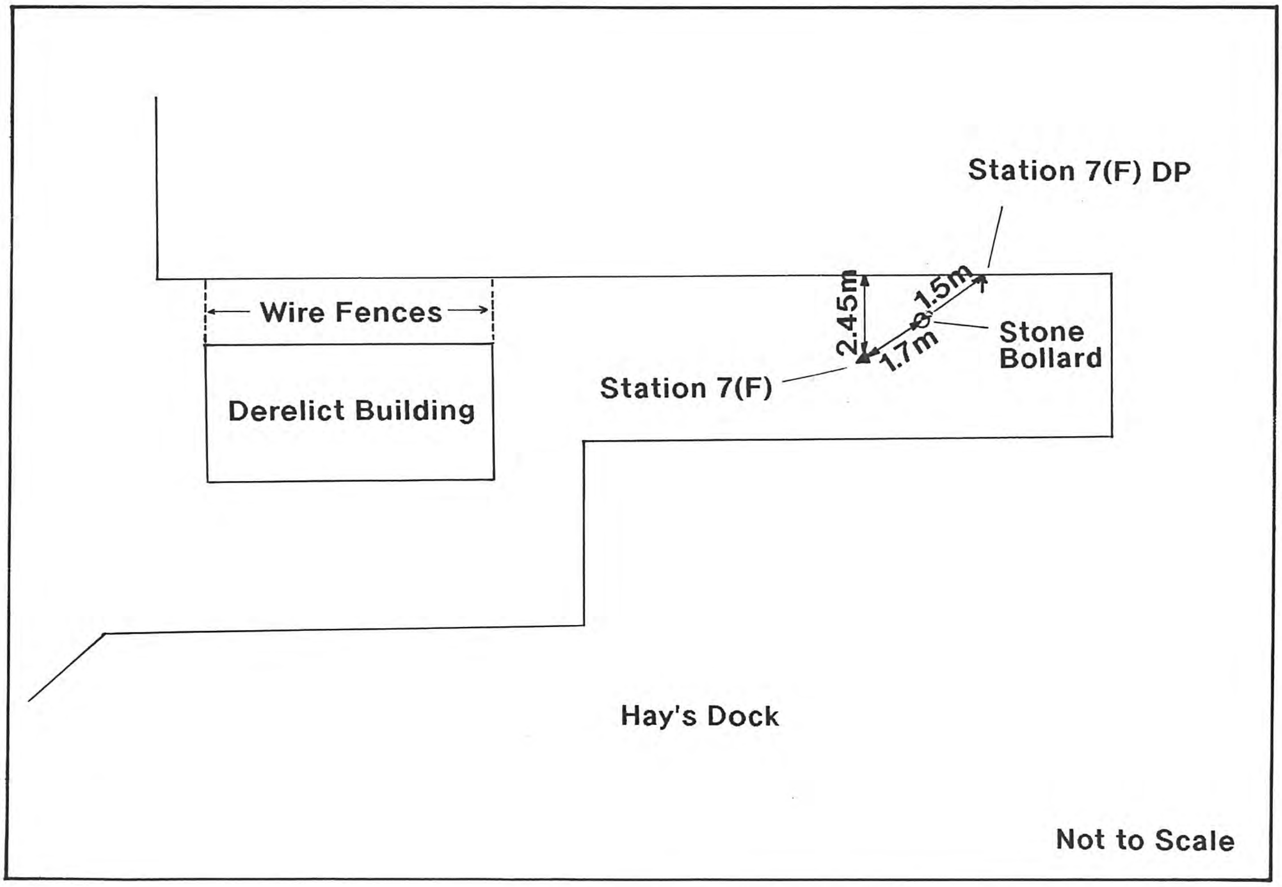


SURVEY STATION INFORMATION

Station Name:	7 (F) DP
Area/Location:	Lerwick, Shetland Islands O.S. 1:50 000 Sheet No: 4
Description of mark:	Rusted metal post approximately 10mm proud of the quay painted yellow
Location of station:	The station is located on a narrow quay (seaward edge) adjacent to Hay's dock
Date of survey:	6th May 1999
Surveyed by:	Caledonian Geotech
Method:	Levelled from station 7(F)
Comments:	The gates of the compound are locked at 17:00

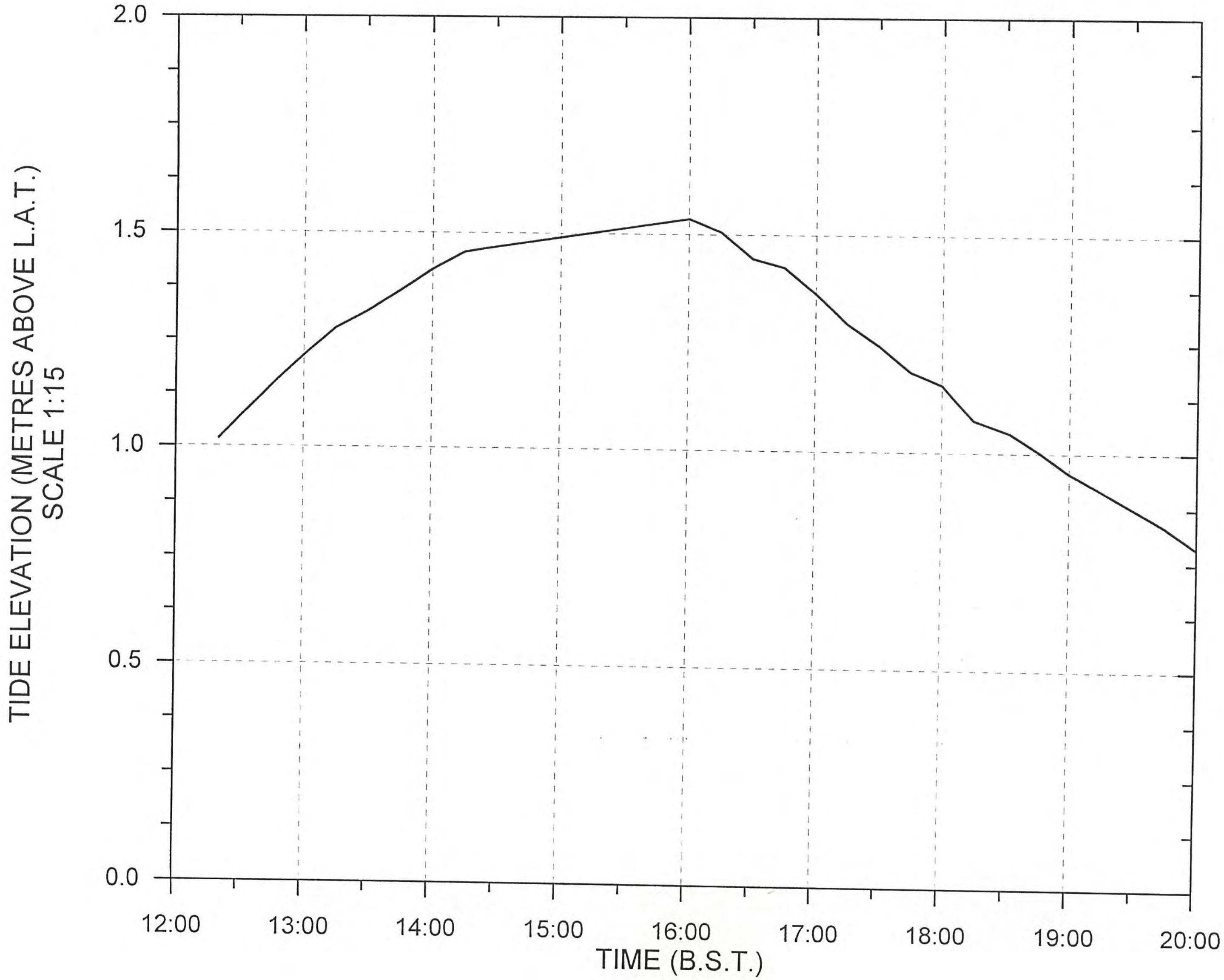
Co-ordinate Information:

Vertical Datum:	O.D. Lerwick
Elevation:	1.286m O.D.

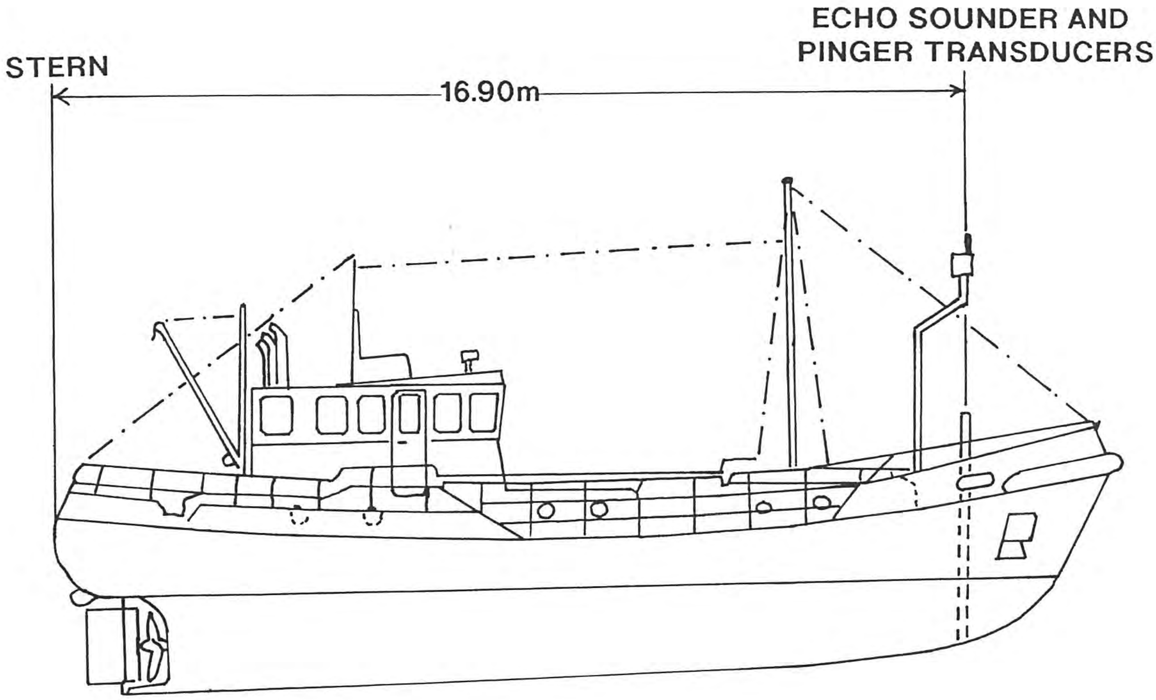


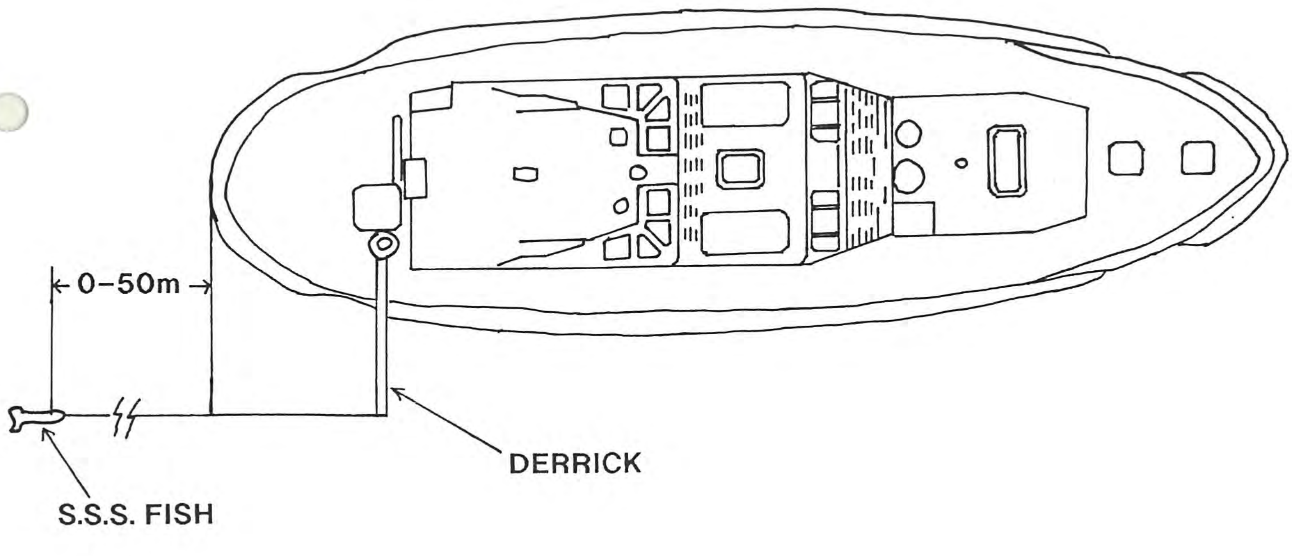
APPENDIX 2.0
TIDE CURVES

CALEDONIAN GEOTECH S9009
BRESSAY FIXED LINK
TIDAL CURVE FOR 6TH MAY 1999

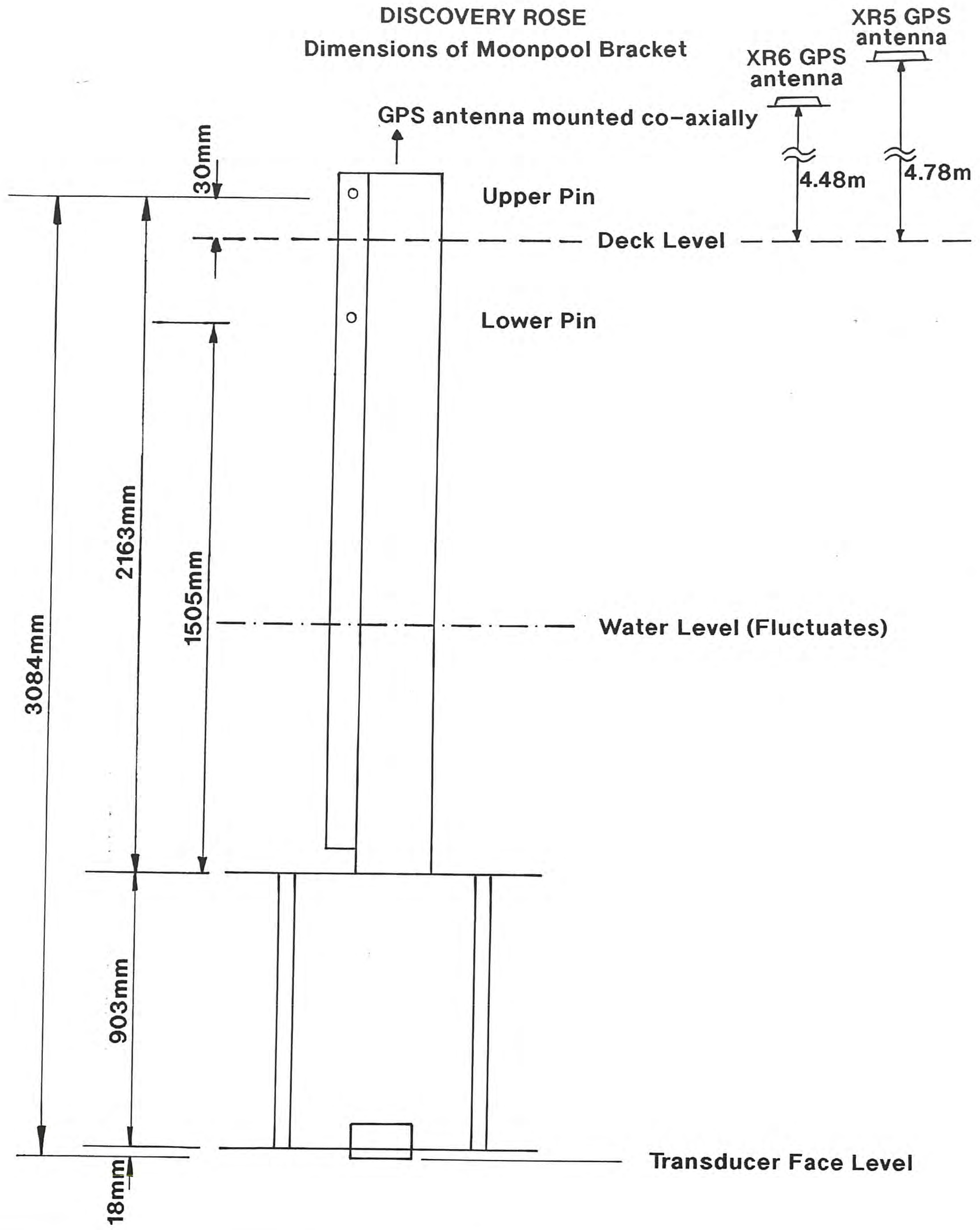


APPENDIX 3.0
SENSOR OFFSETS





R.S. DISCOVERY ROSE : SENSOR OFFSETS



Transducer depth (upper pin) =3054 – Deck to water level

Transducer depth (lower pin) = 2396 – Deck to water level

Worked example : Deck to water level = 1.26m

Upper pin setting

Transducer depth = 3054 – 1260 = 1794

XR6 Height above water = 4.48 + 1.26 = 5.74m

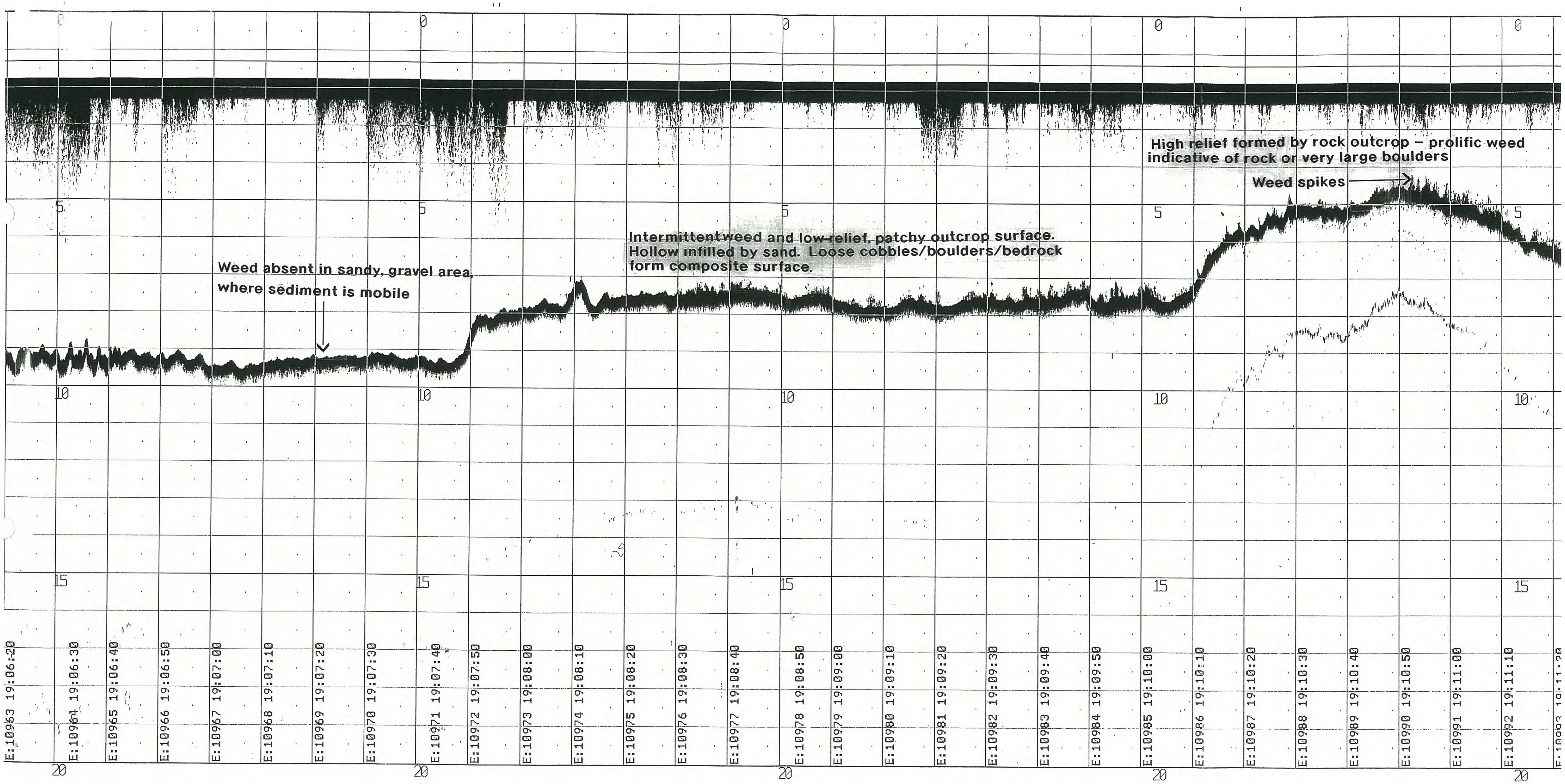
XR5 Height above water = 4.78 + 1.26 = 6.04m

APPENDIX 4.0
DATA EXAMPLES

APPENDIX 5.0
DRAWINGS

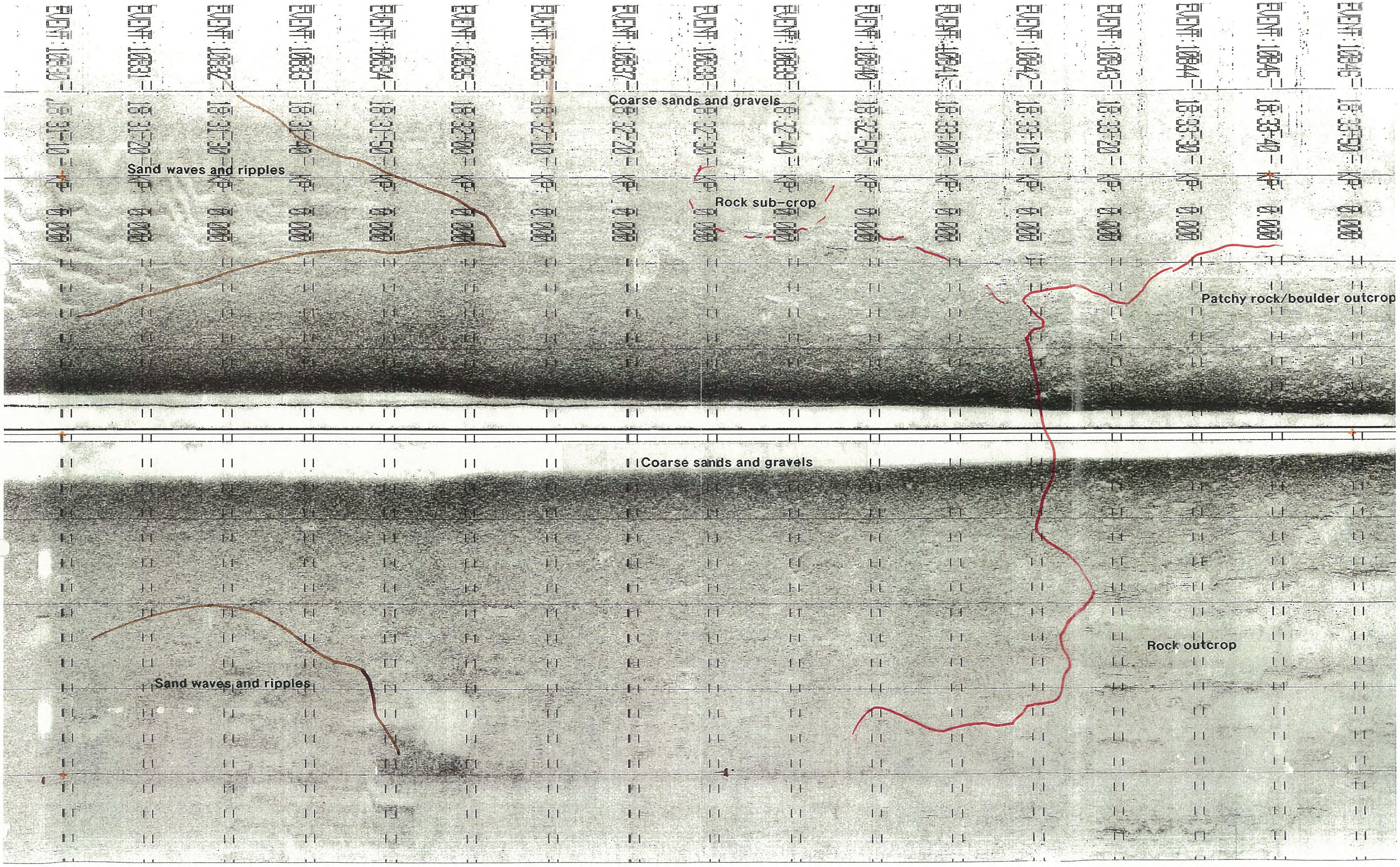
PROPOSED BRESSAY BRIDGE CROSSING SURVEY

Data Example – Echo Sounder



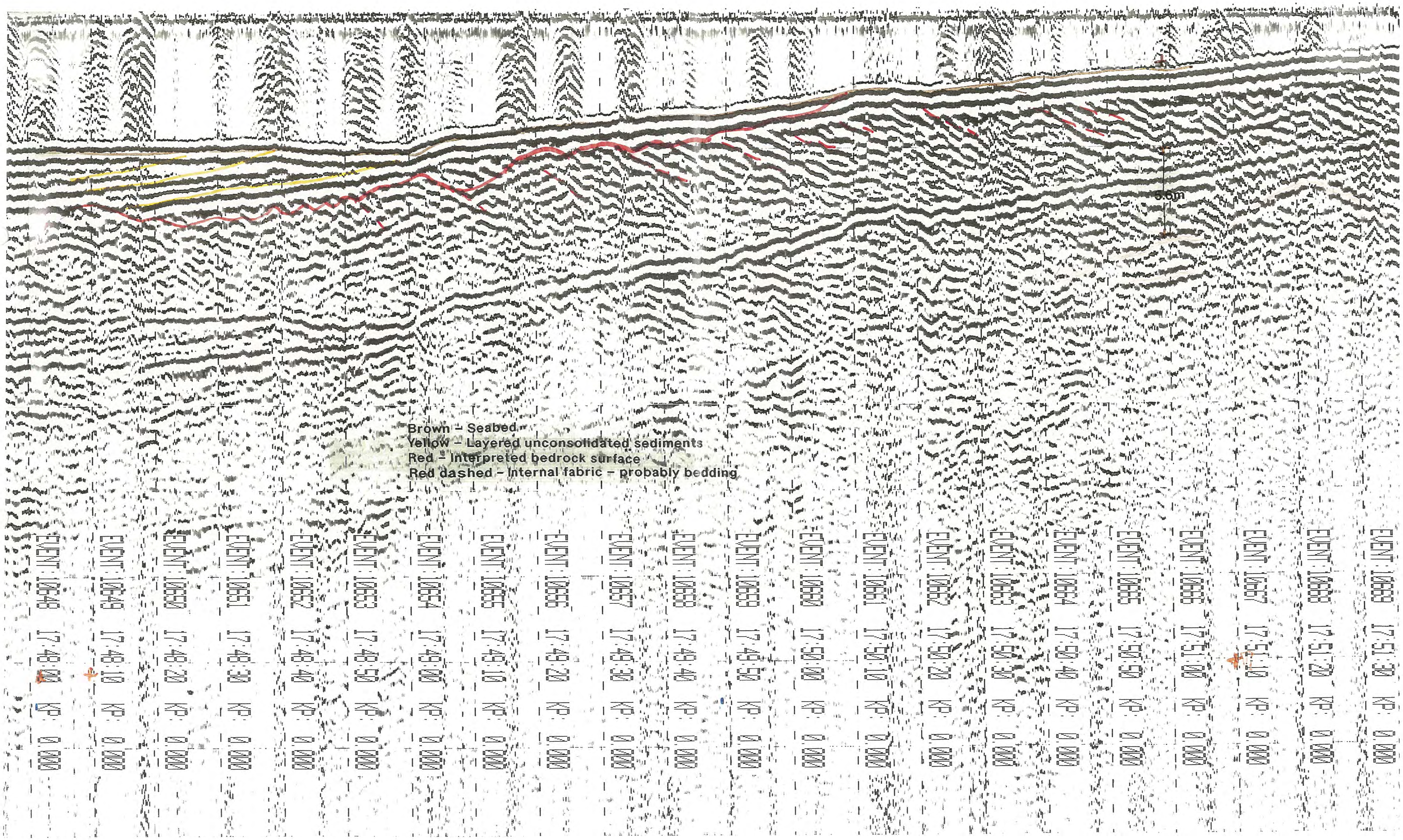
PROPOSED BRESSAY BRIDGE CROSSING SURVEY

Data Example – Side Scan Sonar



PROPOSED BRESSAY BRIDGE CROSSING SURVEY

Data Example – Sparker



PROPOSED BRESSAY BRIDGE CROSSING SURVEY

Data Example – Pinger