



Bressay Fixed Link Geophysical Survey

Report (CS0070/D1/1)

Titan Environmental Surveys Ltd
Coastal Surveys



**Titan Environmental Surveys Ltd
Coastal Surveys**

for

SEACORE Ltd

Bressay Fixed Link Geophysical Survey

Report

Report Number CS0070/D1/1

May 2003

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1. INTRODUCTION

1.1 General

Titan Environmental Surveys Limited was commissioned by Seacore Limited to undertake a survey for the purpose of assessing the seabed and shallow sub-seabed conditions for the installation of the Bressay fixed link between Lerwick and the Isle of Bressay in Shetland.

This report details the survey activities undertaken consisting of a single beam echosounder survey, side scan sonar survey, sub bottom profiler survey and land geophysical survey. The land geophysical survey was subcontracted to Terradat. The Terradat report is contained in Appendix E.

The aim of this report is to present details of the instruments and methods adopted for the surveys and calibration/verification data. The results are presented as charts in Appendix F.

2. INSTRUMENTS AND METHODS

2.1 Integrated Navigation and Data Acquisition System

The navigation and data acquisition system was based on Trimble's HYDRO Pro software running on a ruggedised field computer. Interfaced to this system were the primary and secondary positioning systems, echo sounder and heading sensor. Real time navigation and bathymetric data were output to a surveyor's/helmsman's VDU. In addition, position data, analogue fix marks and digital fix information were output to the side scan sonar and shallow seismic sub-bottom profiler.

During survey operations fixes were logged at thirty-second intervals and every 5m along the ground with echo sounder and magnetometer data logged continuously. A typical data acquisition cycle consists of sampling data from the primary and secondary positioning systems and echo sounder, marking the analogue records, computing the position, updating the various screens and logging the raw data and the results.

Following data collection the navigation data were edited and processed using HYDRO Pro to produce a Track Chart for the survey areas to facilitate the interpretation of the survey data.

2.3 Trimble AG132 Receiver

A Trimble AG132 GPS receiver was utilised as the primary navigation system for all vessel based surveying. The GPS and differential antennae are integrated into the same housing, which are linked to the receiver. The AG132 can be configured to receive differential corrections from a specific frequency within the HF band. The system received differential correction data from the general Lighthouse Authority (GLA) reference station at Sumburgh Head (291.5KHz). The quoted horizontal accuracy for the Trimble AG132 system is $\pm 1\text{m}$. A navigation verification was undertaken by setting the system up over a Titan installed control point in Channerwick and comparing the observed positions against the known co-ordinates, for a 10 minute period. The results of this navigation check are included in Appendix C.

The accuracy of the system was verified by comparison against a secondary system providing real-time comparison of the delta east and delta north error calculated within HydroPro. This takes the measured offset distance between the antennae and the observed positions of both primary and secondary navigation systems and calculates the error.

2.4 Trimble 4400 Dual Frequency GPS Receiver

A Trimble 4400 dual frequency GPS receiver was utilised as the secondary navigation system during the survey. The 4400 system works by taking measurements to individual satellites that are marked with unique identifying codes. High precision atomic clocks aboard the satellites to control the generation of these codes and signals. The measurements to each satellite are then combined in real time to generate a very accurate position in both horizontal and vertical planes.

Each satellite transmits two unique codes. These codes are referred to as the C/A code and P code. These codes are modulated onto two carrier waves (L1 and L2). The L1 wave carries both the C/A and P code whilst the L2 wave carries only the P-code. Unlike conventional GPS receivers (which only track L1) the 4400 is a dual frequency system and is able to track both codes simultaneously; this permits very accurate position determination and eliminates the atmospheric errors associated with conventional GPS surveying techniques.

The accuracy of the system was verified by comparison against the primary system providing real-time comparison of the delta east and delta north error calculated within HydroPro. This takes the measured offset distance between the antennae and the observed positions of both primary and secondary navigation systems and calculates the error.

2.5 Odom Hydrotrac Survey Echo sounder and TSS DMS25 Motion Sensor

Bathymetric data were collected using an Odom Hydrotrac echo sounder the specifications for which are given below.

Frequency:	208 kHz
Sounding Rate:	16 per second (max)
Transducer Beam width:	10° (at half power points)
Accuracy:	±(0.5% of indicated depth+2.5cm)

The echo sounder transducer was mounted on a pole on the starboard side of the vessel and the transducer depth (draft) was measured and input to the echo sounder. A DMS-25 motion sensor was rigidly mounted as near as possible to the echo sounder transducer. The horizontal offsets of the transducer from the primary navigation antenna were also measured and input to HYDRO Pro, which compensates for these offsets during each data collection cycle. The accuracy of

the draft and velocity offsets were checked daily via the bar check method and cross-checked via a temperature/salinity probe to verify the sound velocity figure input into the echo sounder.

The bar-check method involves suspending a metal plate or bar-check at various depths below the echo sounder transducer over the range of depths expected in the survey area. The echoes received from the bar check are then used to adjust the speed of sound input to the echo sounder.

The bathymetric data were corrected for heave and the corrected depths recorded digitally by HYDRO Pro and on the echo sounder trace. The trace was annotated at the start and end of each survey line with details of the line name and with fix marks at thirty second intervals detailing the fix number and time. The echo-sounder roll comprised traces of raw and heave corrected depth as well as the heave line.

The digitised data from each survey line were checked using a graphical editor included with HYDRO Pro to view and, if required, to edit any erroneous data points. Editing of the bathymetric data was limited to the removal of obviously erroneous data points and either interpolation of single bad data points or manual input of data derived from the paper trace. Bathymetric data was reduced to Chart Datum using predicted tides derived using the UK Admiralty Simplified Harmonic Method software TideCalc from Lerwick.

Following editing of the bathymetric data were exported as ASCII text files and thence split into individual line files.

2.6 Edgetech DF-1000 Side Scan Sonar System

Seabed mapping was achieved using an Edgetech DF1000 dual frequency digital side scan sonar, which comprises a digital control unit, communications/tow cable, and tow fish. The system operates at both 105 and 309 kHz, so that the operator may choose which frequency is passed to the thermal printer. The data were recorded on an EPC model GSP-1086 grey scale printer displaying fused data from both frequencies. Other specifications for the system are given below:

Frequency:	105kHz $\pm$ 10kHz and 309 kHz $\pm$ 20 kHz
Horizontal Beam width:	1.2° (105 kHz) and 0.5° (309 kHz)
Vertical Beam width:	50° adjustable
Range per Channel:	25 - 1000m

The side scan system was operated at a range of 50 metres for the duration of data acquisition. The side scan fish was towed from the port side of the vessel and the layback was adjusted depending on the water depths encountered. The data was optimised by adjusting the altitude of the fish by changing the length of cable paid out and reducing the vessels speed over the ground. Annotation to the paper record was provided automatically from HYDRO at thirty-second intervals and included details of the fix number, time, and line name.

2.7 Applied Acoustics Surface Tow Boomer System

Sub-bottom data were collected using an Applied Acoustics Surface Tow Boomer system. The transmitter array comprises a capacitor bank, tow cable and catamaran containing the boomer plate. The receiving array consists of a hydrophone that was input to an Octopus 360 sub bottom data acquisition and processing module. Raw data was stored as sequential date stamped files to hard disc and later renamed to line name and backed up to CD. Online the system applied band pass filtering, time varied filtering, TVG amplification and simple stacking routines. The data were output to an EPC chart recorder, which displays data across a width of 26.5cm. The system was configured as follows:

Power Output: 100 – 200 Joules
Fire Rate: 450 ms
Recorder Sweep: 60ms
Digital Data Sweep: 100ms

The boomer catamaran and hydrophone were towed alongside of the survey vessel to starboard and port respectively and were separated by approximately 4m. The offsets of the tow point from the echo sounder were measured for use in the interpretation of the data.

Each profile record was annotated at the start and end of each survey line with all relevant information. Fix marks were produced and annotated automatically by HYDRO Pro every 30 seconds. Changes to the tuning of the data to compensate for varying sediment types were annotated manually on the data record.

Quality control of data in the field was achieved by monitoring the quality of the profiles as the survey work progressed.

2.9 Octopus 360 Sub-Bottom Processor

The Octopus 360 system operates in real-time and allows the acquisition of high resolution digital data. The system features an on-line display allowing quality control of the data, and data can be stored digitally and/or sent to an external plotting device. The system also allows the facility for data playback and re-processing.

The system was configured to record a single seismic data channel to a data drive to facilitate continuous recording. Navigation was provided to the system at one second intervals from the main navigation computer running Trimble HydroPro software and the 360 system output to an EPC1086 thermal recorder for real time hardcopy recording of the data

Typical configuration settings on the 360 system during the survey were as follows:

Power source: 100 Joules

Fire rate: 450ms

Amplification: x2

Time variable gain 1= 10ms

Time variable gain 2= 500ms

Low pass filter = 5050Hz

High pass filter= 500Hz

3. REFERENCE CONTROLS

3.1 General

All times quoted in this report are in UTC, units of measurement refer to the metric system and all co-ordinates are referred to Ordnance Survey National Projection.

3.2 Horizontal Control

As previously mentioned, a Trimble Ag132 was used for horizontal positioning and the receiver was verified over a coordinated point prior to work commencing.

3.3 Vertical Control

Bathymetry data was reduced to Chart Datum using predicted tides for Lerwick. The Admiralty software Tidecalc was used to predict the tides.

4. SURVEY OPERATIONS

4.1 Summary of Survey Activities

Summaries of the principal survey activities are given in Table 4.1.1 below, and detailed descriptions of the activities from day to day were presented as Daily Logs during operations, copies of which were e-mailed to all parties concerned.

Table 4.1.1 Summary of Principal Survey Activities

Day Numbers	Dates	Activity
1	2 April 2003	Travel S.Wales to Dundee
2	3 April 2003	Travel Dundee to Aberdeen and onward to Shetland
3	4 April 2003	Arrive Lerwick and mobilise vessel
4	5 April 2003	Complete mobilization and perform survey
5	6 April 2003	Nav buoy coordination, grab samples and line re-runs
6	7 April 2003	Await ferry and commence return travel to S.Wales

4.2 Survey Vessel

The C&R Diving vessel *Hegrie*, was used for all survey work. The vessel is fully MCA (Maritime and Coastguard Agency) compliant.

4.3 Safety

All work was carried out in accordance with Titan's *Code of Safe Working Practice*. During the survey at 1345 hrs on the 5 April 2003 the survey vessel ran aground. The vessel was manoeuvred free and work re-commenced without damage to equipment or personnel.

5.0 RESULTS

5.1 Bathymetry

The details of the bathymetry are shown on chart CS0070/D1/V1. Depths during the survey ranged from 0.3m above chart datum in the east of the survey area to 6.9m below chart datum. Generally the survey area was characterised by a channel of depths not exceeding 6.9m in the centre of the area with gradually shelving sides to the east and west.

5.2 Seabed Features

The interpretation of the seabed features is based on the side scan sonar data and correlation with Admiralty Charts (ref 1), the acquired bathymetry and supplied details of the results of the borehole data acquired by Seacore during the geotechnical survey elements of this project. The seabed at the margins of the channel between the Mainland and the island of Bressay are characterised by the presence of exposed bedrock. This has been identified as weathered sandstone and conglomerate. On the margins of the dredged channel the seabed consists of a matrix of silty, sandy gravel and gravelly sand with abundant cobbles and boulders and possible bedrock exposure. In the channel itself the seabed is of silty, sandy gravel and gravelly sand with some cobbles and possible boulders.

Two cables have been identified in the area although they cannot be mapped across the whole site due to the highly reflective and irregular nature of the seabed on the sonar records and the poor resultant contrast between the cable and the seabed. The position of the cables should be treated with caution.

5.3 Shallow Geology

Interpretation of the shallow geology is based on an acoustic velocity of 1600 m/sec for the surficial sediments and acquired surface tow boomer data. Interpretation has been correlated with supplied details of the results of the borehole data acquired by Seacore during the geotechnical survey elements of this project and with the results of a land geophysical refraction seismic survey conducted by TerraDat (ref 2) as a sub-contractor to Titan to link onshore boreholes (BH2) with the offshore survey (BH6 and BH9). The results of the boomer survey were generally poor due to the gravelly nature of the surficial sediments and penetration into the bedrock would be expected to be shallow. However, the boomer data does correlate well with the borehole data in that offshore it consistently indicates generally 1-1.5 metres of silty,

sandy gravel and gravelly sand over weathered sandstone or conglomerate bedrock. Onshore results remain consistent with this with up to 2 metres of silty sandy clay and gravel overlying the bedrock (with a further 2 metres of made ground above in BH2). Generally along the shore line the bedrock is very close to the surface or exposed with less than 1 metre of overlying material expected.

5.4 References

- 1) Admiralty Chart 3290, published 1978 with ammendments in 1995 and 1997.
- 2) TerraDat Report 753v.1 Mapping the Rockhead Profile, Bressay Fixed Link, Shetland Islands, April 2003.

Appendix A – Personnel

Personnel

Mark O'Donovan
Euan McNeill

Party Chief
Geophysicist

Appendix B – Daily Progress Reports



Titan Environmental Surveys Ltd

DAILY SURVEY REPORT

FROM:

TO: Seacore Limited
ATTN: Andy Fielding
COPY: Titan Operations
ATTN: Malcolm Houston

Tel: 01656 881222
Fax: 01656 881234

Project No. CS0070

DATE: 03-Apr-03
DPR Number: 2

ATTN:
PROJECT: Bressay Fixed Link Geophysical Survey

GMT

FROM

TO

OPERATIONS

1000

1200

Travel from Dundee to Aberdeen

1700

Departure Aberdeen on ferry bound for Lerwick

WEATHER FORECAST

OBSERVED WEATHER

00:00

06:00

12:00

18:00

Wind

Sea

Swell

Temp

Baro

Visibility

BAR CHECK

Date

Latitude / Easting

Tx Depth

Time

Longitude / Northing

Weather

Max Depth

SUMMARY Hr.h

HOURS

TOTAL

PROGRESS

km

%

OBIDEMOB

12

24

Progress Today :

OPERATIONAL			SBES SSS STB		0.00
NON OPERATIONAL					
WEATHER STANDBY			Progress To Date :		
WEATHER STAND DOWN			SBES SSS STB		0.00
X A WORK AT CLIENT REQUEST					
WAITING ON CLIENT			Additional work today		
			Total additional work		

Comments - TITAN

1) ETA Lerwick, 0800 4th April 2003

Comments - Health and Safety

Comments - Client Rep



DAILY SURVEY REPORT

Titan Environmental Surveys Ltd

FROM: Mark O'Donovan

Project No. CS0070

TO: Seacore Limited

ATTN: Andy Fielding

COPY: Titan Operations

ATTN: Malcolm Houston

Tel: 01656 881222

Fax: 01656 881234

DATE: 04-Apr-03

DPR Number: 3

COPY:

ATTN:

PROJECT: Bressay Fixed Link Geophysical Survey

GMT

FROM TO

OPERATIONS

0730

Arrive Lerwick

0845

Meet vessel operators at vessel Hegre

0900

1930

Mobilise vessel

WEATHER FORECAST

OBSERVED WEATHER

	00:00	06:00	12:00	18:00
Wind				
Sea				
Swell				
Temp				
Baro				
Visibility				

BAR CHECK

Date	Latitude / Easting	Tx Depth
Time	Longitude / Northing	
Weather	Max Depth	

SUMMARY Hr.h

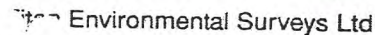
	HOURS	TOTAL	PROGRESS	km	%
OB/DEMOB	12	36	Progress Today :		

OPERATIONAL			SBES SSS STB		0.00
NON OPERATIONAL					
WEATHER STANDBY			Progress To Date :		
WEATHER STAND DOWN			SBES SSS STB		0.00
A WORK AT CLIENT REQUEST					
WAITING ON CLIENT			Additional work today		
			Total additional work		

Comments - TITAN
1) Complete mobilisation tomorrow am

Comments - Health and Safety

Comments - Client Rep



FROM:	Mark O'Donovan	Project No.	CS0070
TO:	Seacore Limited		
ATTN:	Andy Fielding		
COPY:	Titan Operations	Tel: 01656 881222	DATE: 05-Apr-03
ATTN:	Malcolm Houston	Fax: 01656 881234	DPR Number: 4
COPY:			
ATTN:			
PROJECT:	Bressay Fixed Link Geophysical Survey		

[illegible]

WEATHER FORECAST		OBSERVED WEATHER			
		00:00	06:00	12:00	18:00
	Wind			NW3	
	Sea			calm	
	Swell			nil	
	Temp				
	Baro				
	Visibility			good	

BAR CHECK		
Date 05/04/03	Latitude / Easting 447060	Tx Depth 1.03m
Time 0810 GMT	Longitude / Northing 1142880	Velocity 1488 m/s
Weather NW3, sea calm	Max Depth 10m	

SUMMARY Hr.h	HOURS	TOTAL	PROGRESS	
			km	%
OB\DEMOB	0	36	Progress Today :	

OPERATIONAL	12	12	SBES SSS STB		100.00
NON OPERATIONAL					
WEATHER STANDBY			Progress To Date :		
WEATHER STAND DOWN			SBES SSS STB		100.00
EXTRA WORK AT CLIENT REQUEST					
WAITING ON CLIENT			Additional work today		
			Total additional work		

Comments - TITAN

1) Original survey lines complete, plan to rerun some lines tomorrow to try to improve data quality

2) data quality poor due to seabed conditions, gravels and rock preventing seismic penetration

3) numerous navigation buoys observed in survey area, some very close to planned borehole locations

4) power cable navigation marks observed on foreshore, power cables expected to cross survey area

5) strong currents observed in survey area

6) unable to survey across boreholes BH5, BH6, BH13, BH14 - locations very close to foreshore in very shallow water

Comments - Health and Safety

Vessel ran aground at 1345 during survey operations - no damage to personnel, equipment nor vessel. Survey continued in. Immediately following grounding.

Comments - Client Rep



FROM:	Mark O'Donovan	Project No.	CS0070
TO:	Seacore Limited		
ATTN:	Andy Fielding		
COPY:	Titan Operations	Tel: 01656 881222	DATE: 06-Apr-03
ATTN:	Malcolm Houston	Fax: 01656 881234	DPR Number: 5
COPY:			
ATTN:			
PROJECT:	Bressay Fixed Link Geophysical Survey		

[illegible]

WEATHER FORECAST		OBSERVED WEATHER			
		00:00	06:00	12:00	18:00
	Wind			S3	
	Sea			calm	
	Swell			nil	
	Temp				
	Baro				
	Visibility			good	

BAR CHECK		
Date	Latitude / Easting	Tx Depth
Time	Longitude / Northing	Velocity
Weather	Max Depth	

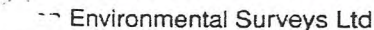
SUMMARY Hr.h	HOURS	TOTAL	PROGRESS		
			km		%
MOBIDEMOB	3.25	39.25	Progress Today :		

OPERATIONAL	8.75	20.75	SBES SSS STB		100.00
NON OPERATIONAL					
WEATHER STANDBY			Progress To Date :		
ATHER STAND DOWN			SBES SSS STB		100.00
EJ A WORK AT CLIENT REQUEST					
WAITING ON CLIENT			Additional work today		
			Total additional work		

Comments - TITAN
1) Navigation buoys at
447249E 1143590N
447120E 1143731N

Comments - Health and Safety

Comments - Client Rep



DAILY SURVEY REPORT

FROM:	Mark O'Donovan	Project No.	CS0070
TO:	Seacore Limited		
ATTN:	Andy Fielding		
COPY:	Titan Operations	Tel: 01656 881222	DATE: 07-Apr-03
ATTN:	Malcolm Houston	Fax: 01656 881234	DPR Number: 6
COPY:			
ATTN:			
PROJECT:	Bressay Fixed Link Geophysical Survey		

[illegible]

WEATHER FORECAST	OBSERVED WEATHER				
		00:00	06:00	12:00	18:00
	Wind				
	Sea				
	Swell				
	Temp				
	Baro				
	Visibility				

BAR CHECK		
Date	Latitude / Easting	Tx Depth
Time	Longitude / Northing	Velocity
Weather	Max Depth	

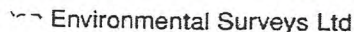
FL	SUMMARY Hr.h	HOURS	TOTAL	PROGRESS		
				km		%
	MOB\DEMOB	12	51.25	Progress Today :		

OPERATIONAL		20.75	SBES SSS STB		100.00
NON OPERATIONAL					
WEATHER STANDBY			Progress To Date :		
WEATHER STAND DOWN			SBES SSS STB		100.00
A WORK AT CLIENT REQUEST					
WAITING ON CLIENT			Additional work today		
			Total additional work		

Comments - TITAN

Comments - Health and Safety

Comments - Client Rep



FROM:	Mark O'Donovan	Project No.	CS0070
TO:	Seacore Limited		
ATTN:	Andy Fielding		
COPY:	Titan Operations	Tel: 01656 881222	DATE:
ATTN:	Malcolm Houston	Fax: 01656 881234	08-Apr-03
COPY:			DPR Number:
ATTN:			7
PROJECT:	Bressay Fixed Link Geophysical Survey		

[illegible]

WEATHER FORECAST		OBSERVED WEATHER			
		00:00	06:00	12:00	18:00
	Wind				
	Sea				
	Swell				
	Temp				
	Baro				
	Visibility				

BAR CHECK		
Date	Latitude / Easting	Tx Depth
Time	Longitude / Northing	Velocity
Weather	Max Depth	

SUMMARY Hr.h	HOURS	TOTAL	PROGRESS		
OB\DEMOB	12	63.25	Progress Today :	km	%

OPERATIONAL		20.75	SBES SSS STB		100.00
NON OPERATIONAL					
WEATHER STANDBY			Progress To Date :		
WEATHER STAND DOWN			SBES SSS STB		100.00
A WORK AT CLIENT REQUEST					
WAITING ON CLIENT			Additional work today		
			Total additional work		

Comments - TITAN

Comments - Health and Safety

Comments - Client Rep

Appendix C – Navigation Verification

Project Name: Bressay Fixed Link
Occupied Station: Shet2
Network Info: Titan installed point 06/10/00
Datum:

Project Code: CS0070
Station Code:
Date Occupied: 07/04/03
Ellipsoid: WGS84

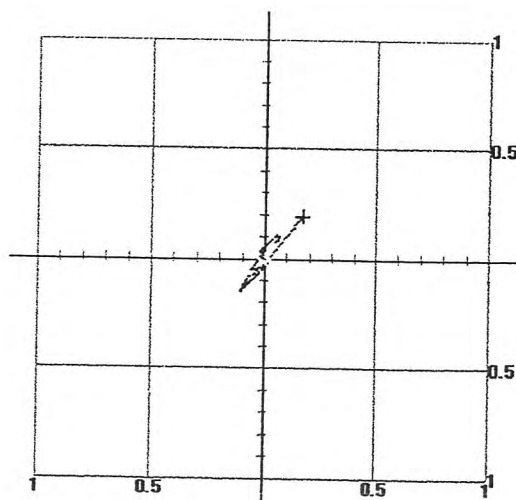
Latitude: 59°59'36.70776"N Longitude: 01°16'41.69525"W
Height: 98.886m

Receiver: Trimble ag132
Frequency: 291.5 kHz
Position Info:

Equipment Used
Differential Mode: Differential
Differential Station Name: Sumburgh Head

Variable	Current	Average
2D Distance	0.260m	0.101m
3D Distance	0.261m	0.169m
Delta North	0.194m	0.000m
Delta East	0.173m	0.000m
Delta Up	-0.018m	0.000m
Bearing	41.62°	149.96°
HDOP	1.00	1.34
VDOP	0.00	0.00
PDOP	0.00	0.00
Latitude	59°59'36.71430"N	59°59'36.70802"N
Longitude	1°16'41.67648"W	1°16'41.68762"W
Height	100.520m	100.538m
Positioning	Differential	100.00% differential
Ref Distance		
Sigma N:	0.093m	Sigma E: 0.068m
Sigma Up:	0.133m	Sigma 2D: 0.115m
Sigma 3D:	0.176m	
Positions:	647	Duration: 00:10

Scatter Plot:



Current: 59°59'36.71430"N 1°16'41.67648"W
Average: 59°59'36.70802"N 1°16'41.68762"W
1 Sigma: 0.115m 2 Sigma: 0.231m 3 Sigma: 0.346m
Positions: 647 Duration: 00:10

Appendix D – Echosounder Calibrations

Velocity
1488

Blanking
1.1

Draft
1.03

Time
03:04:02

Units are meters

Date
23/11/01

Gauge
0.0

5

10

15

Units are meters

5/4/03

0810

4470606

11428802

5

10

15

Time
03:04:02

Units are meters

Date
23/11/01

Gauge
0.0

Draft
1.03

Blanking
1.7

Velocity
1488

Appendix E – Terradat Report

GEOPHYSICAL SURVEY REPORT

PROJECT

MAPPING THE ROCKHEAD PROFILE

LOCATION

**BRESSAY FIXED LINK
SHETLAND ISLANDS**

CLIENT

TITAN ENVIRONMENTAL SURVEYS LTD



geophysical innovation

Head Office
Ocean House
Hunter Street
Cardiff Bay
Cardiff Cf10 5FR
United Kingdom

Tel: +44 (0)8707 303050
Fax: +44 (0)8707 303051
www.terradat.com

Job Reference 753
April 2003
Version 1

1. INTRODUCTION

This report describes a geophysical survey carried out on behalf of Titan Environmental Survey Ltd as part of the ground investigation study for the proposed road link between the main Shetland Island and Bressay. The aim of the survey was to provide information on the rockhead profile between a series of borehole locations.

2. SURVEY DESCRIPTION

The geophysical survey was carried out using the P-wave *Seismic Refraction* technique as detailed below.

Survey Description

Seismic refraction data were acquired along four profile lines (Figure 1 & 3) using a high precision 24-channel GEODE seismic system. The seismic signal was generated using a combination of 'Buffalo' gun and sledgehammer sources and recorded via 2m spaced geophone/hydrophone arrays.

The profile lines were positioned to avoid areas that would degrade the quality of the seismic data (e.g. loose pebbles, riprap) and areas that conflicted with on site factory activity (e.g. storage and transport of goods).

Background

Refraction surveying involves the observation of seismic signal that has been refracted at a geological boundary between a high velocity layer and an overlying lower velocity layer. Shots are deployed at the surface and recordings made via a linear array of sensors (geophones or hydrophones). Refracted seismic signal travels laterally through the higher velocity layer (refractor) and generates a 'head-wave' that returns to surface. Beyond a certain distance away from the shot, the signal that has been refracted at depth is observed as first-arrival signal at the geophones. Observation of the travel-times of refracted signal from selectively deployed shots enables derivation of the depth profile of the refractor layer. Shots are typically fired at locations at and beyond both ends of the geophone spread and at regular intervals along its length.

Recorded data are downloaded to a computer for analysis of the seismic first-arrival times to each geophone from all shot positions in order to construct travel-time versus distance graphs. Depths to refractor layer profiles (geological boundaries) are produced by an involved analysis procedure based on consideration of shot and receiver geometry, travel-times and calculated velocities. The final output

of a seismic refraction survey is a depth profile of the individual refractor layers and a velocity model of the subsurface that is interpreted in terms of the local geological setting.

P-wave seismic surveys employ fast travelling compressional waves that are generated by an impacted plate at surface or a small explosive device in a shallow hole. Typical target boundaries for a P-wave refraction survey include (i) the base of weak soils / fill, (ii) the water table, (iii) the top of compact sediment units such as a till, (iv) rockhead.

Shear (S) wave seismic surveys employ slow travelling shear waves which are generated by a surface mounted device (coupled to the ground by its own weight or by fins) which is struck sideways by a hammer or a swung weight. Clays and water have little to no shear strength so clay rich sediments and the water table do not refract S-wave signal. In places where compact clay-rich tills and/or shallow water overly weak bedrock an S-wave survey may be used profile rockhead where insufficient velocity contrast may prevent use of a P-wave survey.

Constraints

Layer velocity (density) must increase with depth; true in most instances. Layers must be of sufficient thickness to be detectable. Data collected directly over loose fill (landfills) or in the presence of excessive cultural noise may result in sub-standard results. Single narrow fractures are too small to be detected.

3. RESULTS & DISCUSSION

The results of the seismic refraction survey are presented in Figures 2 in the form of interpreted seismic velocity boundaries. For reference purposes, published tables that relate seismic P-wave velocity to diggability/rippability are provide in Appendix A.

The following interpretation is based on correlation of observed seismic velocities with standard values and when the borehole information becomes available, the sections cab be further calibrated.

Line 1

The seismic data reveal the presence of 3 significant layers that are interpreted as thin near surface weak material (~300m/s), unconsolidated material/weathered bedrock (~1000m/s) and a competent bedrock unit (~3400m/s). The interpreted bedrock refractor is relatively planar and is at or near the surface for the northern half of the survey line. As the ground level rises towards the shoreline (southwest), the depth to the bedrock refractor increases to approximately 2.5m below ground level (bgl) at the base of the riprap structure.

Line 2

Processing of the acquired seismic data was complicated by a shallow localised low velocity zone, which suggests the presence of low density/poorly compacted materials. Given the position, this low velocity zone is probably associated with the installation of the adjacent buried services. The interpreted bedrock refractor is generally planar and is at or near the surface for the eastern end of the survey line. Bedrock appears to vary in depth of between 3-4m bgl, and exhibits a corresponding increase in elevation as the ground level rises shoreward (west).

Line 3

The processed section suggests that bedrock resides at or near the surface for the entire length of the survey line, which correlates to observations made at site.

Line 4

This line extends across the factory yard and suggests rockhead depths of approximately 3-4m bgl, which correlates to the observations from BH-2. Over the central region, the velocity of the main overlying unit (857 m/s) suggests the presence of dry unconsolidated material. There appears to be an increase in the thickness of thin weak near-surface material (~300m/s) towards both end of the profile line.

4. CONCLUSIONS AND RECOMMENDATIONS

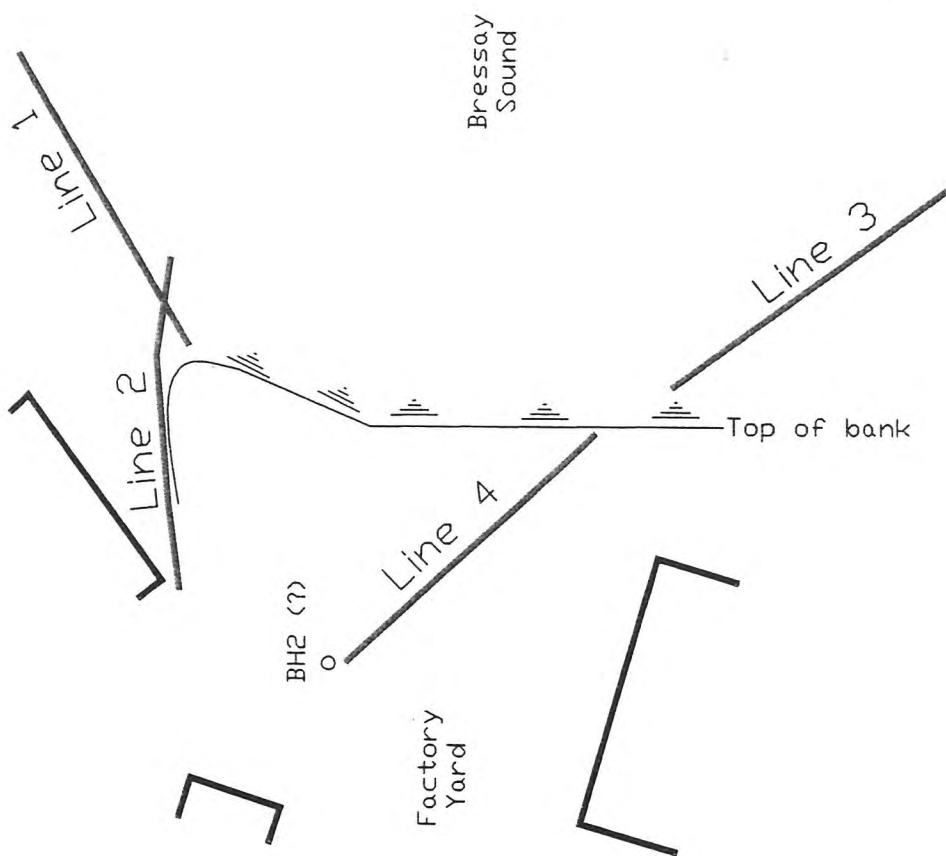
- Geophysical surveys have provided a high-resolution, rapid and non-invasive means for investigating the subsurface along the specified profile lines.
- A depth profile for the competent seismic refractor (~3500m/s) has been derived and appears to vary between approximately 0-4m below ground level.
- For each identified geophysical feature that may be of concern, it is recommended that an intrusive investigation be carried out in order to provide geological ground truthing.

Disclaimer

This report represents an opinionated interpretation of the geophysical data. It is intended for guidance with follow-up invasive investigation. Features that do not produce measurable geophysical anomalies or are hidden by other features may remain undetected. Geophysical surveys compliment invasive/destructive methods and provide a tool for investigating the subsurface; they do not produce data that can be taken to represent all of the ground conditions found within the surveyed area. Areas that have not been surveyed due to obstructed access or any other reason are excluded from the interpretation.



Approximate



25m

Bressay Fixed Link
Shetland Islands

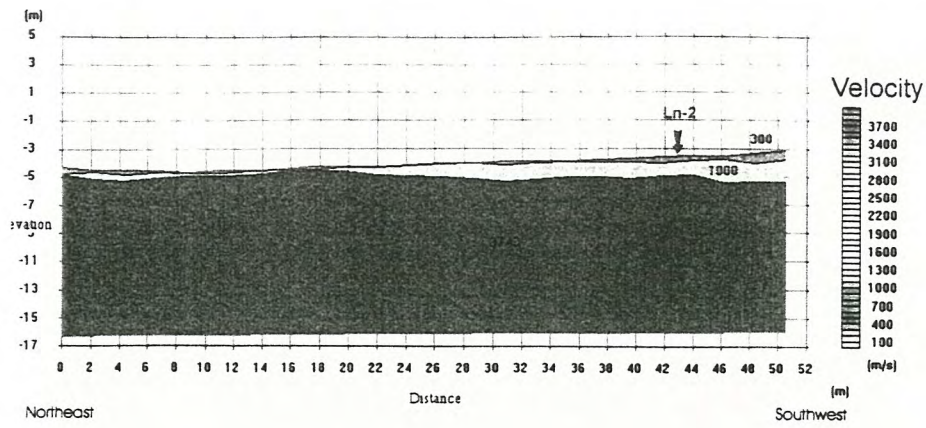
Location of Survey Lines

TERRADAT (UK) LTD

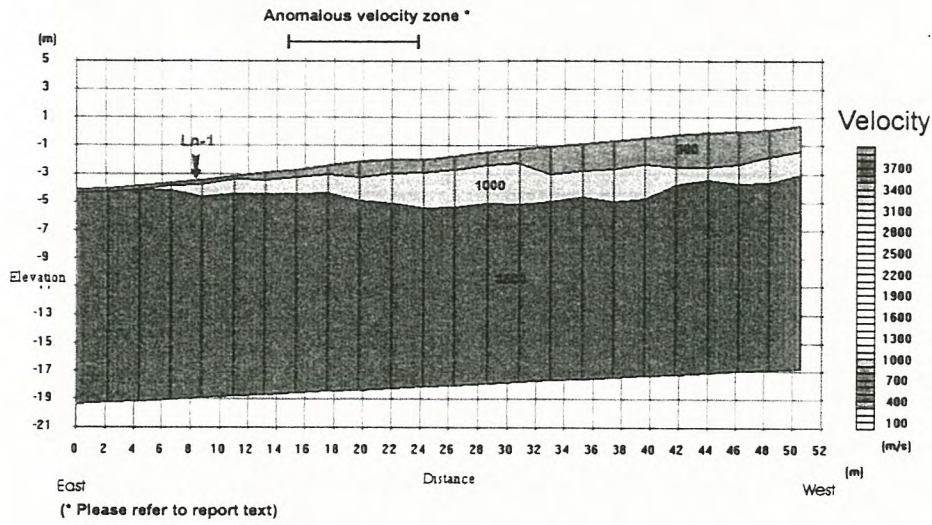
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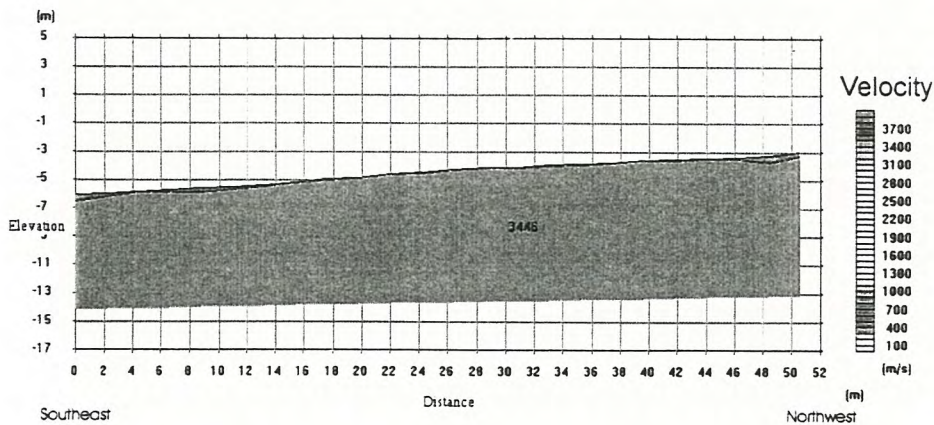
Figure 1



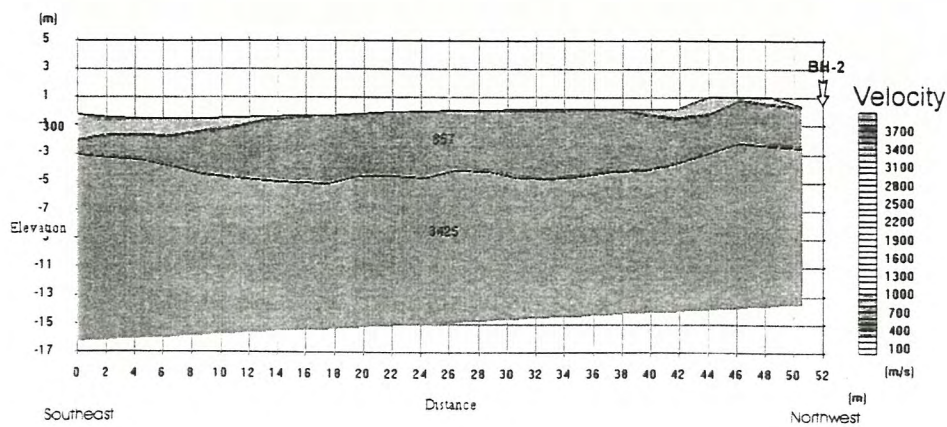
Line 1



Line 2



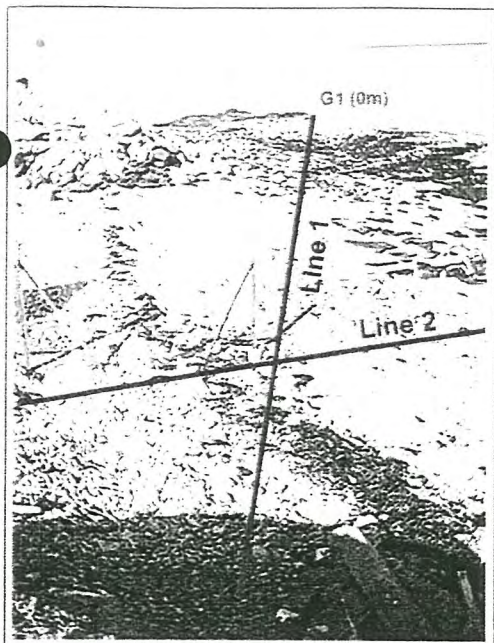
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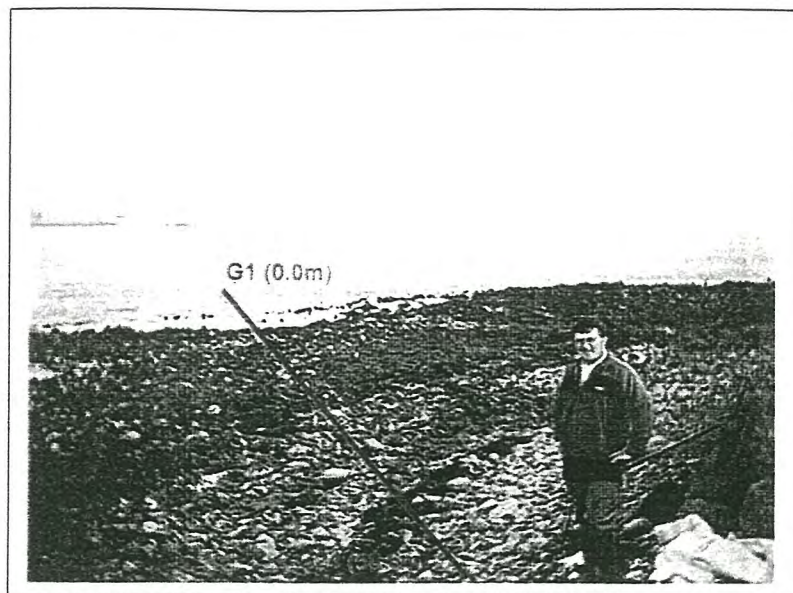
Line 4

Seismic Refraction
BRESSAY FIXED LINK SHETLAND ISLANDS
TERRADAT (UK) LTD

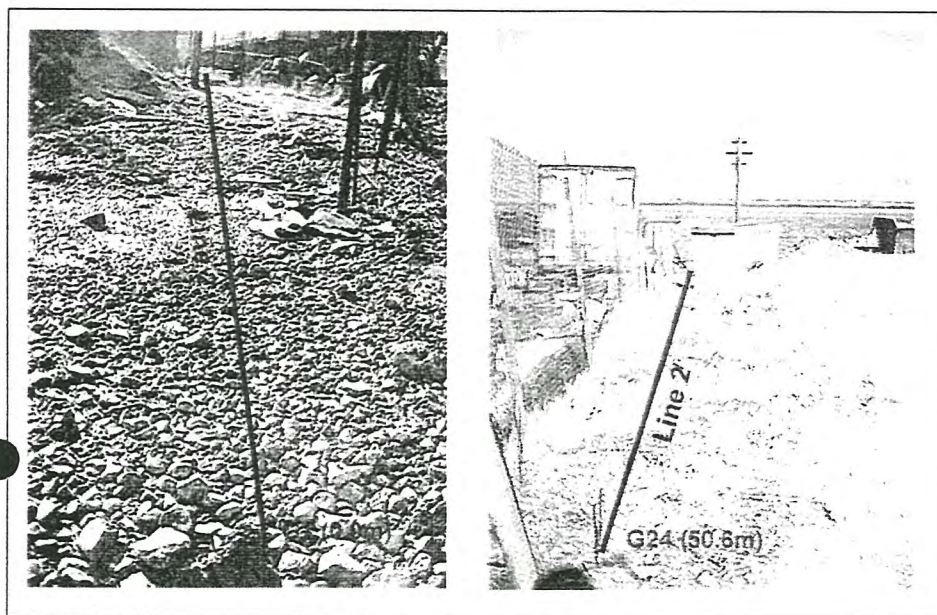
Figure 2



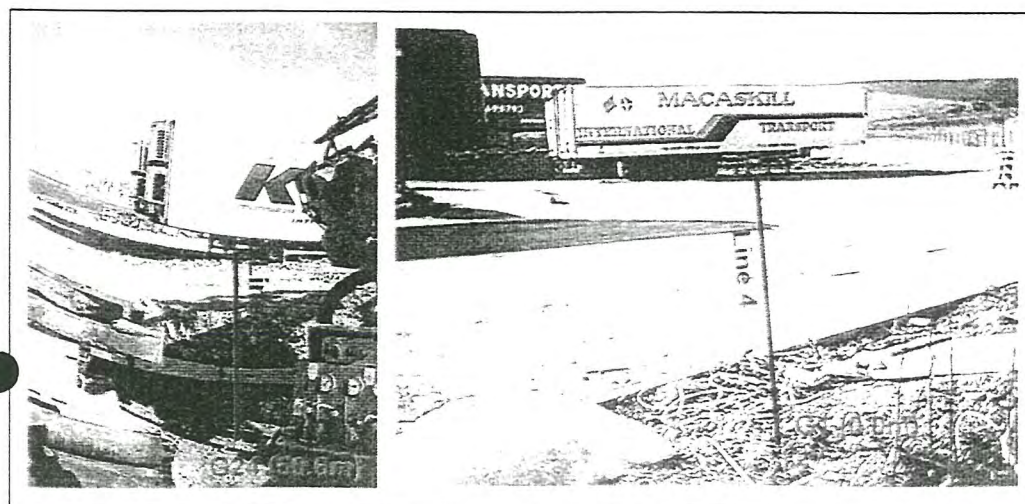
(a) Line 1



(c) Line 3



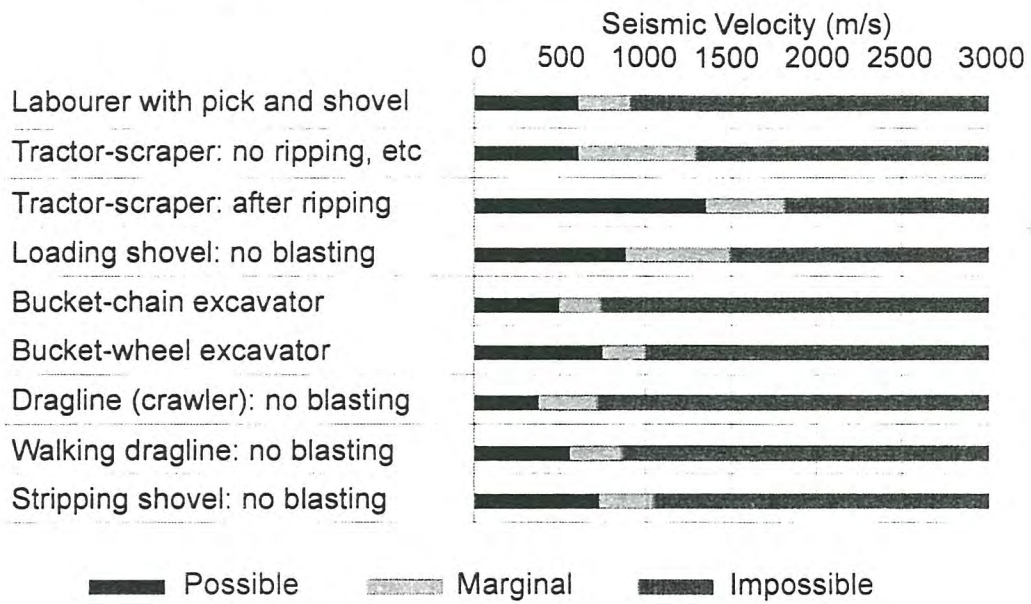
(b) Line 2



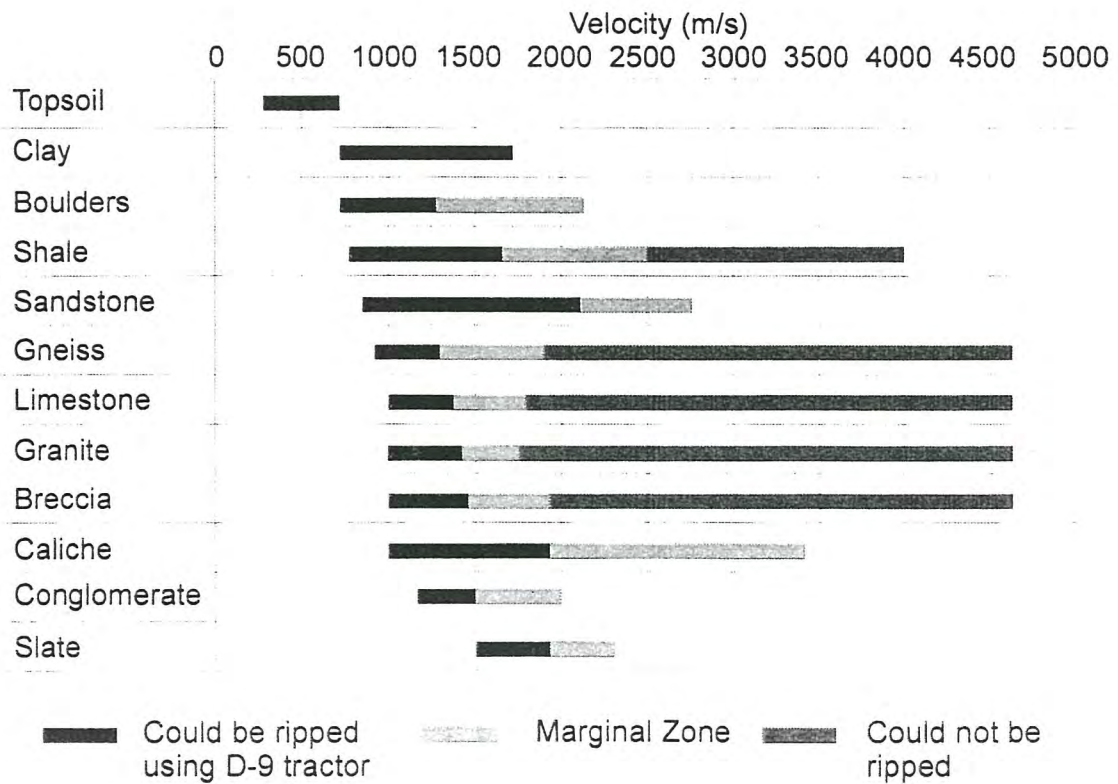
(d) Line 4

Seismic Refraction Lines
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Seismic velocities for determining diggability (Atkinson, 1971)



Rippability Chart (Geology and Construction, 1995)



Appendix F – Charts