Appendix 5:
Belmullet Wave Energy Connection, Belderra Strand County Mayo - Geophysical Survey Report Status

Belmullet Wave Energy Connection

Belderra Strand County Mayo

Geophysical Survey

Report Status: Draft

MGX Project Number:5500

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10th November 2010

Confidential Report To:

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Report submitted by : Minerex Geophysics Limited

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Geophysics Limited

Subsurface Geophysical Investigations

EXECUTIVE SUMMARY

1. Minerex Geophysics Ltd. (MGX) carried out a geophysical survey consisting of Seismic Refraction surveying for the Belmullet Wave Energy Connection project at Belderra Strand in County Mayo.
2. Eleven pairs of seismic profiles were acquired ~ parallel to the seafront and extended from just above high water mark as far as possible towards the low water mark.
3. The survey penetrated to > 15m Below Ground Level (BGL) and shows a three layer earth model below the site.
4. The overburden consists of a soft / loose layer of sand and shingle at the back of the beach. This layer has low seismic velocities, is 1.2 – 6.0m thick and could be excavated by digging.
5. A second thicker overburden layer also consists mainly of sand and shingle. This layer extends across the site and is 2.0 – 15m thick. It has higher seismic velocities and is more compact but could still be excavated by digging. Some possible thin weathered rock, that may need to be excavated by ripping, may be present at the base of the layer.
6. The deepest layer consists of strong rock which has a high seismic velocity of 3.7 – 3.8km/s. This rock could be extracted by breaking / blasting.
7. The depth to the top of the strong rock varies between ~ 2.0 – 15.0m BGL. The rock is shallowest in the west and far southeast of the site and deepest in the north.
8. A narrow ridge of strong rock approximately 10m wide with a depth range of 2.0 -6.0m is well defined on the seismic datasets along the western fringe of the site. Here the rock shallows towards the outcrop just southwest of the site.
9. Any future landfall cables which are installed as part of the Wave Energy Connection project should be positioned where the sand and shingle sequences are thickest in the central or eastern part of the site. This will reduce the amount of breaking / blasting of strong rock required in the excavation phase of the project, or breaking may be avoided completely.

CONTENTS

List of Tables, Maps and Figures:

1. INTRODUCTION

1.1 Background

Minerex Geophysics Ltd. (MGX) carried out a geophysical survey for the Belmullet Wave Energy Connection Project. The survey consisted of acquiring Seismic Refraction datasets at the southwest end of Belderra Strand near Belmullet. The survey was commissioned by ESBI acting in conjunction with the Sustainable Energy Authority of Ireland (SEAI). The ESBI and SEAI are developing a number of wave energy test facility sites off shore Belmullet. The survey was designed to cover a landfall site for a subsea cable at Belderra Strand.

1.2 Objectives

The main objectives of the geophysical survey were:

- To establish the optimum trenching corridor between the low water mark and the high water mark.
- To determine the ground conditions under the site
- To determine the depth to rock and overburden thickness
- To estimate the strength/stiffness/compaction of overburden materials and the quality of rock

1.3 Site Description

The test site covers a 1.7Ha site of open beach at the southwest end of Belderra Strand.

1.4 Geology

The bedrock geological map of North Mayo, (GSI, 1992), indicates that the Belderra Strand Area of Mayo is underlain by Precambrian lithologies. These rocks consist of banded crystalline grey gneiss. The map also shows an anticlinal structure and a fault lying to the southeast of the site (GSI, 1992).

1.5 Report

This report includes the results and interpretation of the geophysical survey. Maps, figures and tables are included to illustrate the results of the survey. More detailed descriptions of geophysical methods and measurements can be found in GSEG (2002), Milsom (1989) and Reynolds (1997).

The client provided a map of the site and the digital version was used as the background map in this report.

The interpretative nature and the non-invasive survey methods must be taken into account when considering the results of this survey and Minerex Geophysics Limited, while using appropriate practice to execute, interpret and present the data, give no guarantees in relation to the existing subsurface.

2. GEOPHYSICAL SURVEY

2.1 Methodology

The methodology was given by ESBI and consisted of Seismic Refraction data acquisition.

In the seismic refraction survey method a p-wave is generated by a source at the surface resulting in energy travelling through surface layers directly and along boundaries between layers of differing seismic wave velocities. Processing of the seismic data allows geological layer thicknesses and boundaries to be established.

The seismic survey consisted of p-wave seismic refraction profiling. Each of the profiles consisted of 24 geophones with 2 m spacing, resulting in lengths of 46m per profile. The data was acquired with two profiles end to end giving a combined profile length of 94m. Eleven pairs with a general spacing of 15m were acquired across the site. In total 22 profiles were recorded. The recording equipment consisted of a Geometrics ES3000 seismograph with 10 Hz vertical geophones. The seismic energy source consisted of a hammer and plate. A zero delay trigger was used to start the recording. At least 7 shot points per p-wave profile were used.

All locations and elevations were surveyed to Irish National Grid with a Magellan ProMark 500 RTK system.

Table 1: Data Acquisition Parameters for Geophysical Profiles

Profile Name	Geophone Interval/m	Number of Geophones	Profile Length/m	Approximate Penetration Depth/m
S1 – S22	2	24	46	17m

Seismic Refraction generally determines the depth to layers where the compaction/strength/rock quality changes with an accuracy of 10 – 20% of depth to that layer.

2.2 Site Work

The data acquisition was carried out between the 20th and 22nd of October 2010. The weather conditions were variable throughout the acquisition period. Health and safety standards were adhered to at all times.

The survey was conducted during a Spring Low Tide in order to extend the survey as far as possible towards the sea. Strong westerly winds and a large swell prevented acquisition of datasets further out the beach.

3. RESULTS AND INTERPRETATION

The interpretation of geophysical data was carried out utilising the known response of geophysical measurements, typical physical parameters for subsurface features that may underlay the site, and the experience of the authors.

3.1 Seismic Refraction Data

The seismic refraction data was positioned and processed with the SEISIMAGER software package to give a layered model of the subsurface. The number of layers has been determined by analysing the seismic traces and 3 layers were used in all models. All seismic profiles were subject to a standardised processing sequence which consisted of a topographic correction which was based on acquired elevation data, first break picking, tomographic inversion, travel-time computation via ray-tracing and velocity modelling. Residual deviations of typically 0.7 to 2.1 msec RMS have been obtained for each profile. Following each processing stage QC procedures were adhered to. The resulting layer boundaries are shown as thick lines on interpretive cross sections (Figure 1a – 1f). The seismic velocities obtained within the layers are annotated on the sections. The seismic velocities indicate the change of compaction / stiffness / rock quality with depth.

Table 2 summarises the interpretation. The compaction/strength/rock quality has been estimated from the seismic velocity. The estimation of the excavatability for the bedrock has been made according to the caterpillar chart published in Reynolds (1997). The geotechnical assessment for rippability will have to take factors like rock type and jointing into account and the estimation in this report is solely based on the seismic velocities.

Layer 1 has a thickness of 1.2 – 6.0m and seismic velocities of 0.6 – 0.9 km/s. This consists of soft / loose sand and shingle and is present in the southernmost part of the site only. This layer of sand and shingle is less inundated with sea water and less compacted than further out the beach.

Layer 2 was modelled with a velocity range of 1.7 – 1.8 km/s and has a thickness range of 2.0 – 15.0m. This layer is present across the entire site and consists of firm – stiff / dense sand and shingle. Weathered rock may be present at the base of this layer.

Layer 3 velocities of 3.7 – 3.8 km/s indicate a strong rock. The depth to the top of this layer generally varies between 2.0 and 15.0m below ground level.

Table 2: Summary of Results and Interpretation

Layer	General Thickness Range (m)	Average Thickness (m)	General Seismic Velocity Range (km/sec)	Compaction/ Strength/ Rock Quality	Interpretation	Estimated Excavation Method
1	1.2 - 6.0	4.2	0.6 – 0.9	Soft / Loose	Sand / Shingle	Diggable
2	2.0 – 15.0	11.5	1.7 – 1.8	Firm – Stiff / Dense	Sand / Shingle With possible weathered rock at base	Diggable / Rippable
3	2.0 – 15.0 Depth to top of Layer	11.5 Depth to top of layer	3.7 – 3.8	Strong Rock	Strong Rock (Gneiss)	Breaking / Blasting

3.2 Ground Surface Topography

The ground surface elevation along each seismic refraction profile was recorded with a ProMark 500 RTK system. This data was imported into the SURFER software package and a topographical map was generated (Map 2).

3.3 Elevation of Strong Rock

The elevation of strong rock elevation contour maps (Maps 3 & 4) were constructed using the data results from all of the individual seismic refraction profiles. The 22 datasets were combined and interpolated and contoured using a minimum curvature option in the SURFER software programme. The contours show the elevation in metres to Malin Ordnance Datum (MOD) with the magenta contours depicting areas where the strong rock has maximum elevation and the blue where the rock reaches its minimum elevation. Map 3 shows the data as a line contour map and map 4 shows the same data as a filled colour contour map. The maps show the areas of maximum elevation, ~-3m MOD, are recorded in the southeast and along the western fringe of the site. Minimum elevation of ~-15m MOD, is restricted to the far northeast further out the beach. The most obvious feature shown on the maps is the rapid elevation change over the first 10m from west to east and south to north. Over the rest of the site the decrease in elevation towards the northeast is more gradual.

3.4 Depth to Strong Rock

The depth to strong rock was constructed by subtraction of the elevation of the strong rock layer from the ground elevation for each of the 22 seismic refraction datasets. The data was then combined and interpolated and contoured using a minimum curvature option in the SURFER software programme. The depth to the top of the strong rock in m below ground level (BGL) is displayed in maps 5 & 6. Map 5 shows the data as a line contour map and map 6 shows the same data as a filled colour contour map. The magenta contours depict areas where the strong rock is shallow and the blue contours show where the rock is deepest. The depth to strong rock shows similar results to the maps of the elevation of strong rock. Maps 5 and 6 show the depth to the top of this layer reaches a minimum of ~2m BGL. This is expected as this part of the survey area is close to the rock outcrop bounding the south-western edge of the strand. There is also a localised minimum of ~5m in the far southeast corner of the site. The maps show the overall trend is a rapid deepening of the strong rock to the east and northeast. The maximum depth of ~15m is recorded in the far northeast. The data shows the overburden of sand and shingle thickens towards the shoreline.

4. CONCLUSIONS

The following conclusions are made:

- The geophysical survey carried out at Belderra Strand shows a three layer earth model with thick sequences of sand and shingle overlying strong gneissic rock.
- The overburden contains two distinct layers of sand and shingle. One which is 1.2 – 6.0m thick exists over the southern landward part of the site only. This is a soft / loose layer.
- The underlying firm – stiff / dense sand and shingle layer exists under the whole site. This is 2.0 – 15.0m thick and is thinnest in the west and thickest in the northeast.
- The depth to the strong gneissic lithologies ranges 2.0 – 15.0m. The minimum depth of 2-3m is recorded along a 10m wide corridor on the western edge of the site close to areas of outcrop. Within this corridor the depth rapidly increases to ~8m BGL.
- Over most of the central part of the test site the general depth range to the top of the strong rock is 9 – 13m BGL but while it is a rugose surface it does not show significant rapid depth changes over localised areas.
- While the maximum depth to strong rock of 15m is reached in the far northeast of the site it is known from a previous client acquired marine dataset that the bedrock shallows to about 1m below the seabed ~ 250m offshore.
- The survey shows that if the wave energy connection seabed cable is to make landfall in this area it should be positioned close to the central or eastern part of the site. This is where the sand and shingle, which could be excavated by digging / ripping, is thickest.
- If the cable is to be buried to depths greater than 2m BGL then the western fringe and the far southeast corner of the site should be avoided as breaking / blasting of the strong rock could be required.

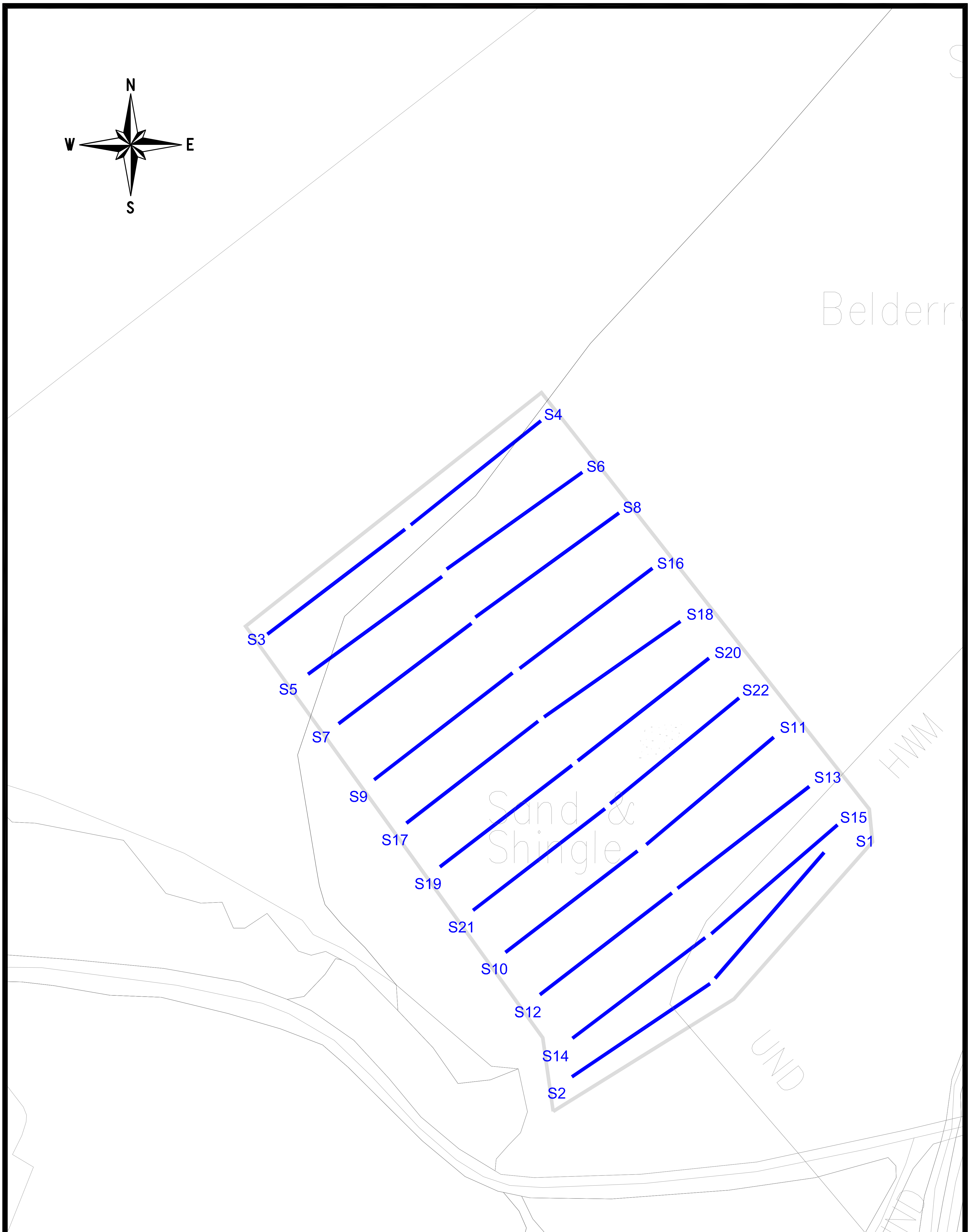
5. REFERENCES

1. **GSEG 2002.** Geophysics in Engineering Investigations. Geological Society Engineering Geology Special Publication 19, London, 2002.

2. **GSI, 1992.** Geology of North Mayo. Geological Survey of Ireland 1992.

3. **Milsom, 1989.** Field Geophysics. John Wiley and Sons.

4. **Reynolds, 1997.** An Introduction to Applied and Environmental Geophysics. John Wiley and Son.



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CLIENT	ESBI SEAI
PROJECT	Belmullet Wave Energy Connection Geophysical Survey
TITLE	Map1 : Location Map of Geophysical Survey

SCALE:	1:1000 @ A3
PROJECT:	5500
DRAWN:	TL
DATE:	05/11/2010
MGX FILE:	5500d_Figs.dwg
STATUS:	Draft

LEGEND:

S1 Seismic Refraction Profile

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CLIENT	ESBI SEAI
PROJECT	Belmullet Wave Energy Connection Geophysical Survey
TITLE	Map 2 : Ground Surface Topography Contour Map in MOD

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S1 Seismic Refraction Profile

Ground Surface Topography in MOD

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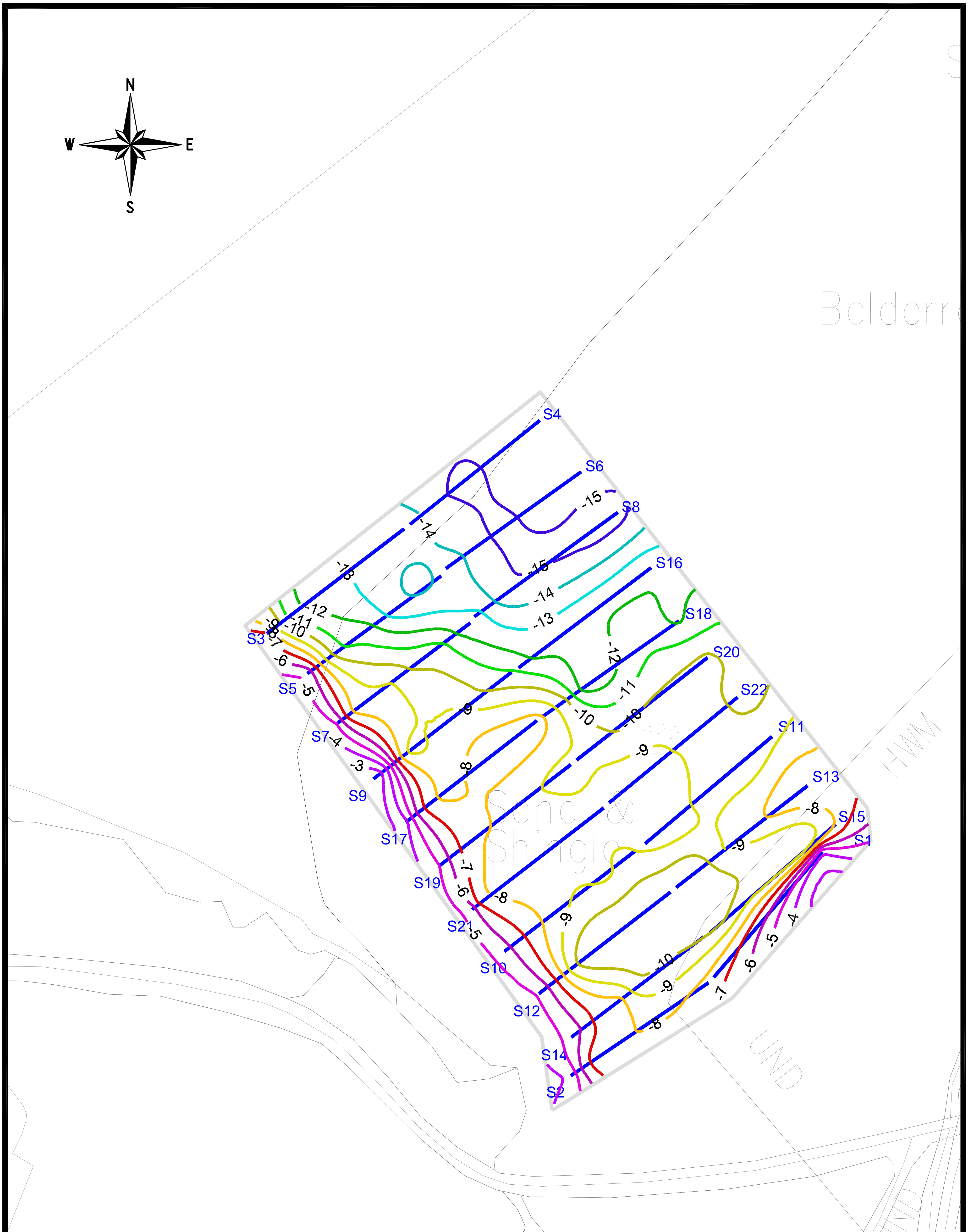

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CLIENT: ESBI
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PROJECT: Belmullet Wave Energy Connection
Geophysical Survey

TITLE: Map 3 : Elevation of Strong Rock
Line Contour Map in MOD

SCALE:	1:1000 @ A3
PROJECT:	5500
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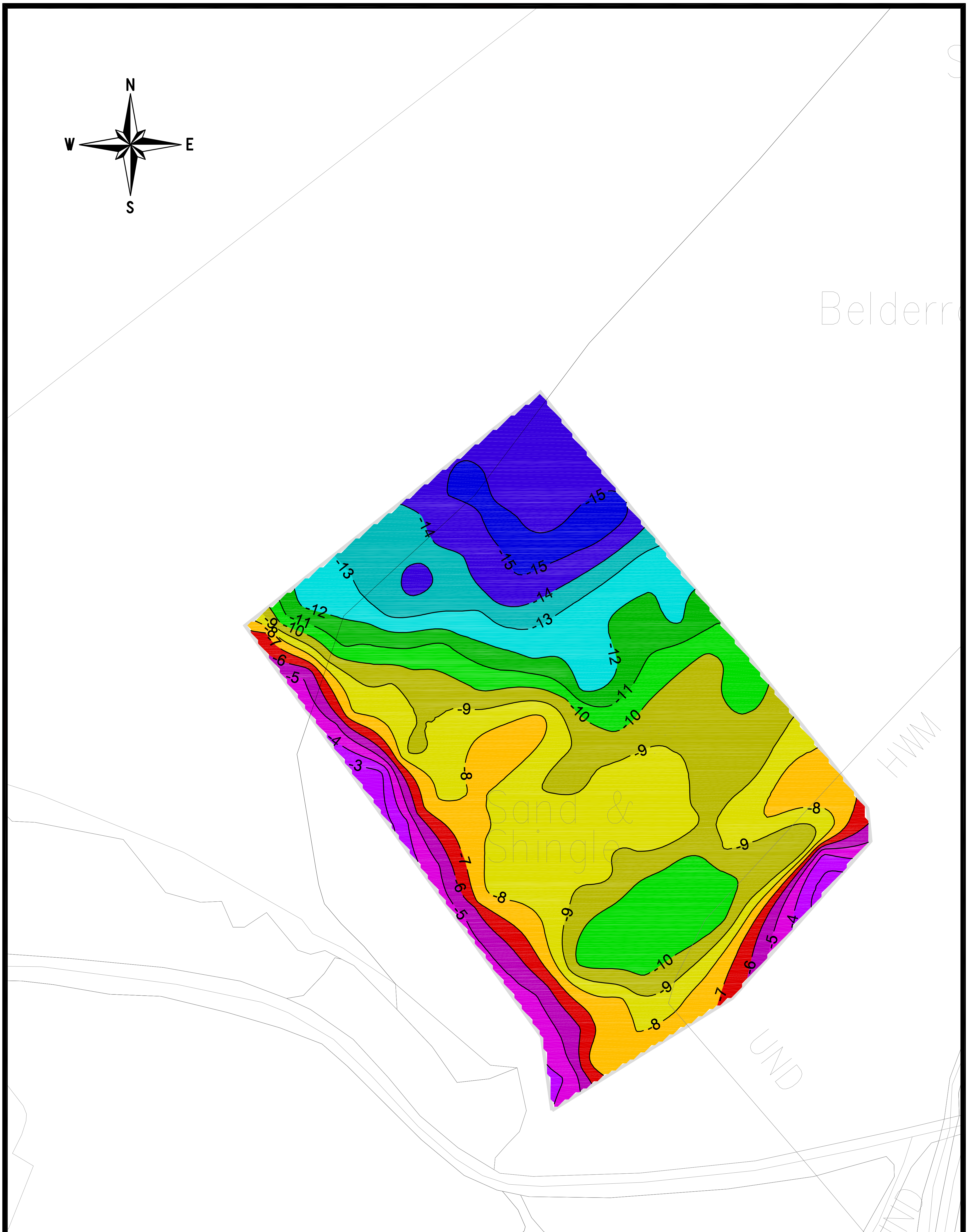
LEGEND:

S1 Seismic Refraction Profile

Elevation in MOD

-3 -4 -5 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16



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CLIENT	ESBI SEAI
PROJECT	Belmullet Wave Energy Connection Geophysical Survey
TITLE	Map 4 : Elevation of Strong Rock Colour Contour Map in MOD

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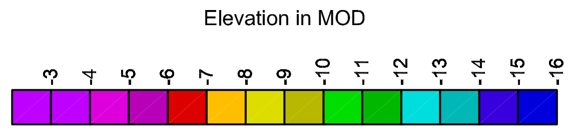

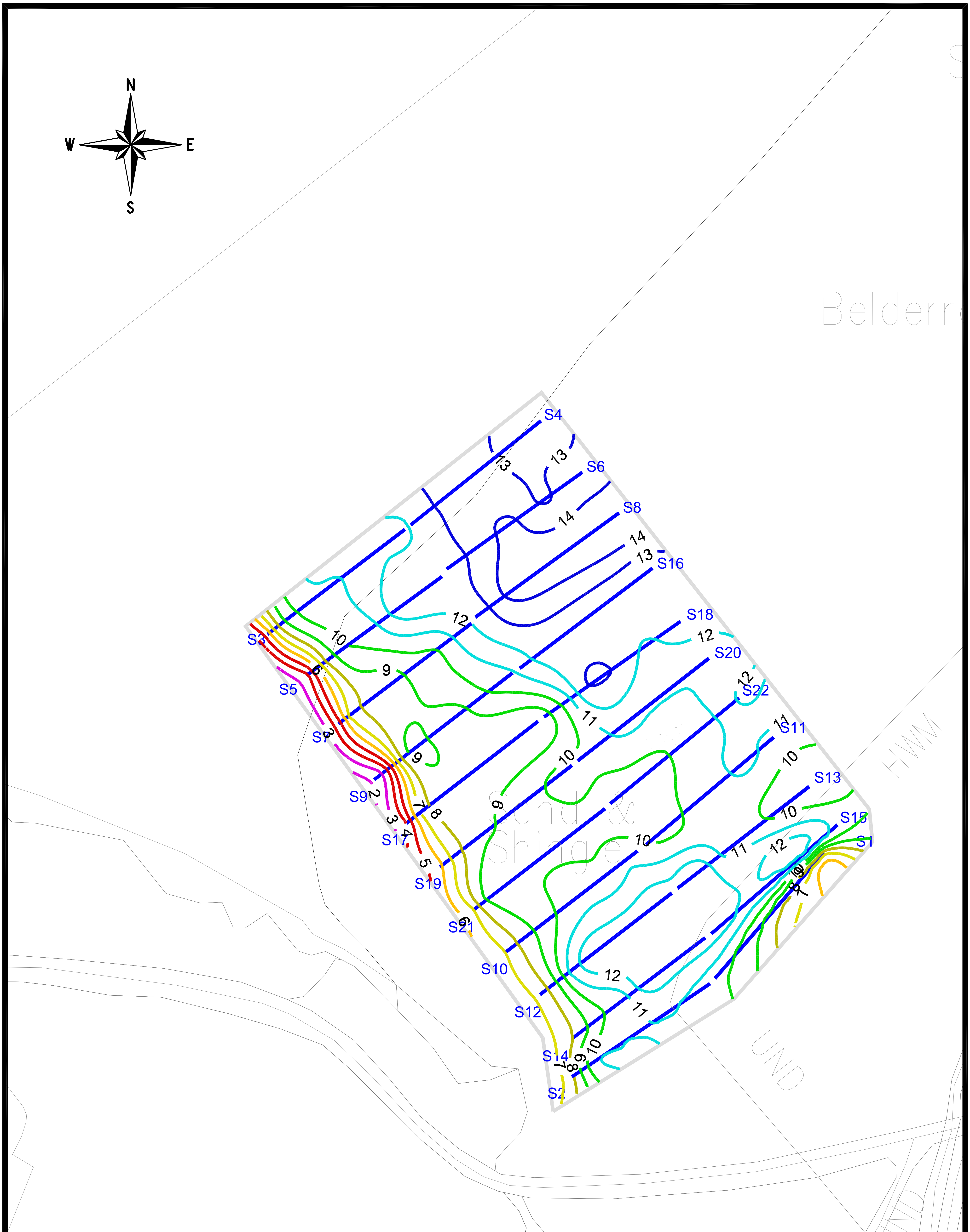

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CLIENT	ESBI SEAI
PROJECT	Belmullet Wave Energy Connection Geophysical Survey
TITLE	Map 5 : Depth to Strong Rock Line Contour Map in m BGL

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PROJECT:	5500
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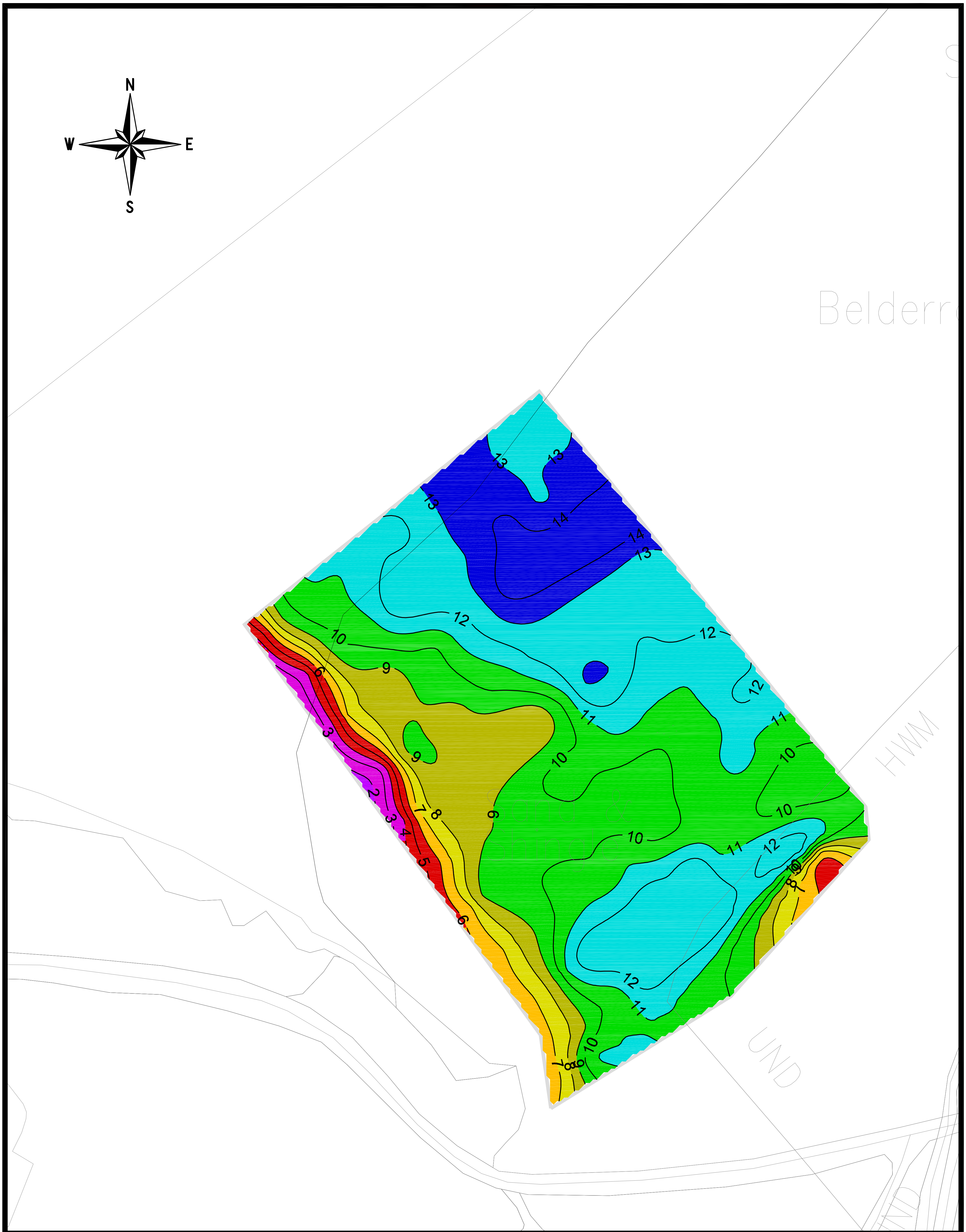
S1 Seismic Refraction Profile

Depth in m BGL

1 2 3 4 5 6 7 8 9 10 11 12 13 14



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CLIENT	ESBI SEAI
PROJECT	Belmullet Wave Energy Connection Geophysical Survey
TITLE	Map 6 : Depth to Strong Rock Colour Contour Map in m BGL

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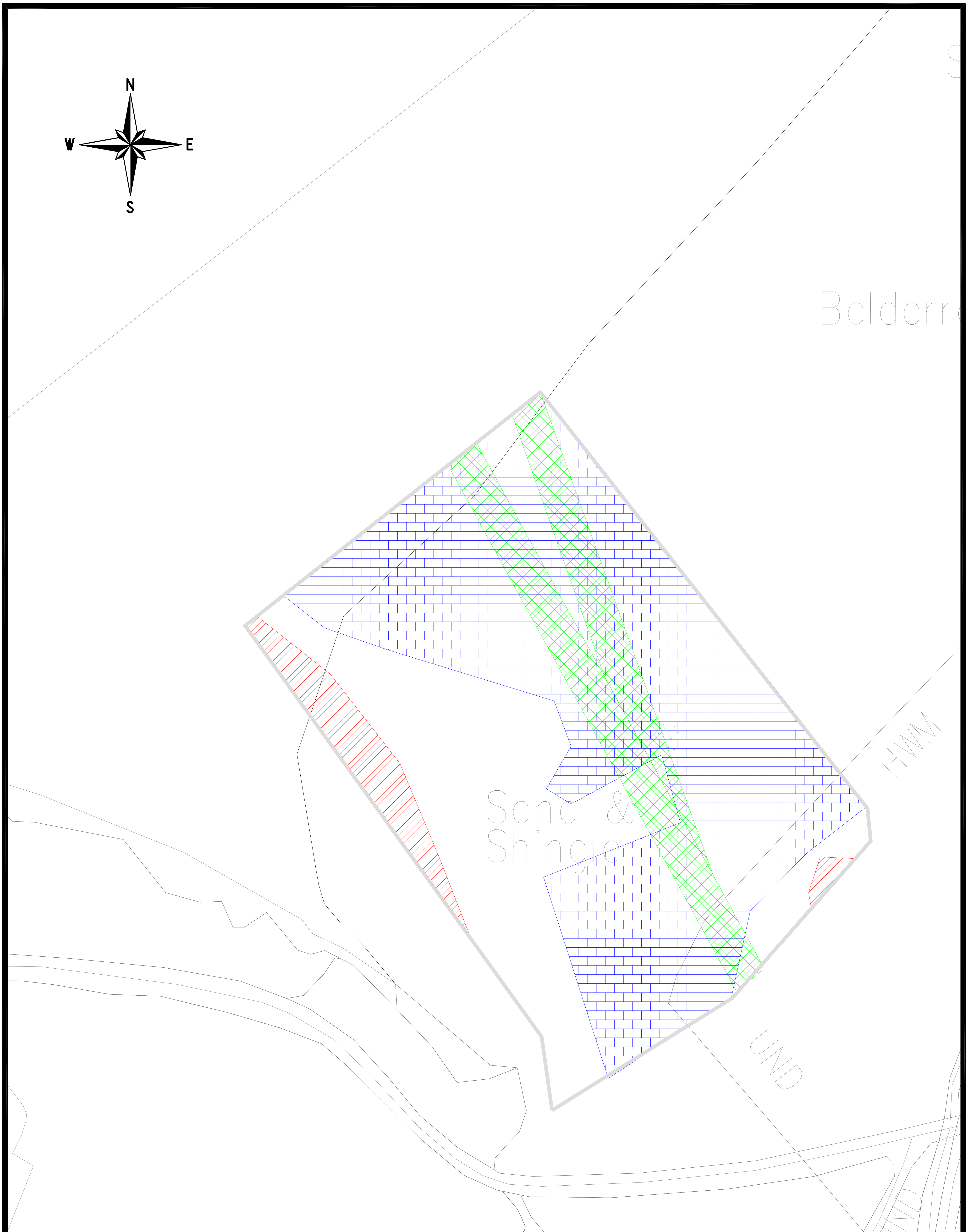
STATUS:	Draft

LEGEND:

Depth in m BGL

1 2 3 4 5 6 7 8 9 10 11 12 13 14



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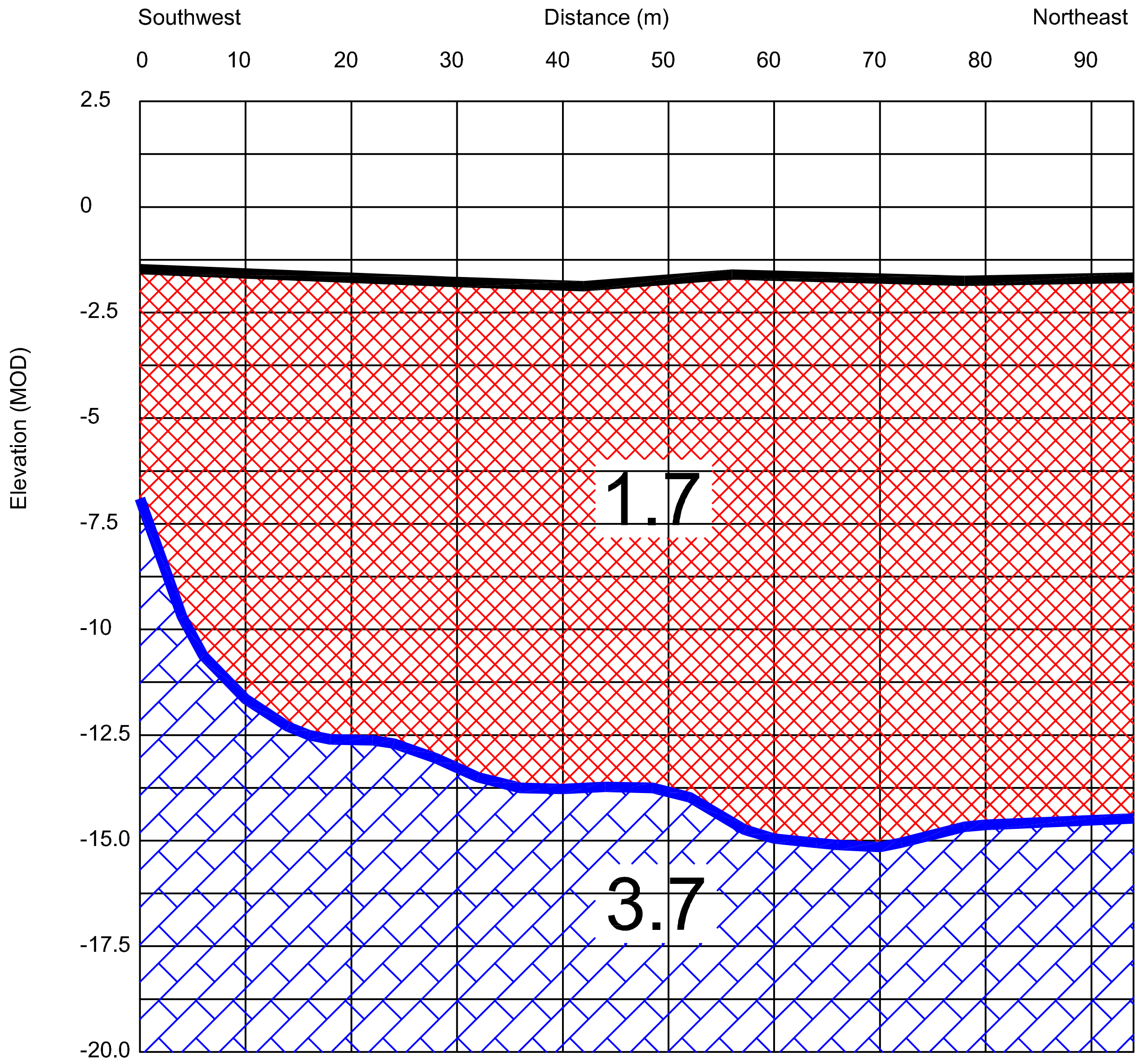
TITLE	Map 7 : Summary Interpretation Map	MGX FILE:	5500d_Maps.dwg
		STATUS:	Draft

LEGEND:

- Areas where depth to Strong Rock is <6m BGL
- Areas where depth to Strong Rock is >10m BGL
- Areas of possible trenching for landfall cables

Seismic Refraction Profiles S3 & S4 Model



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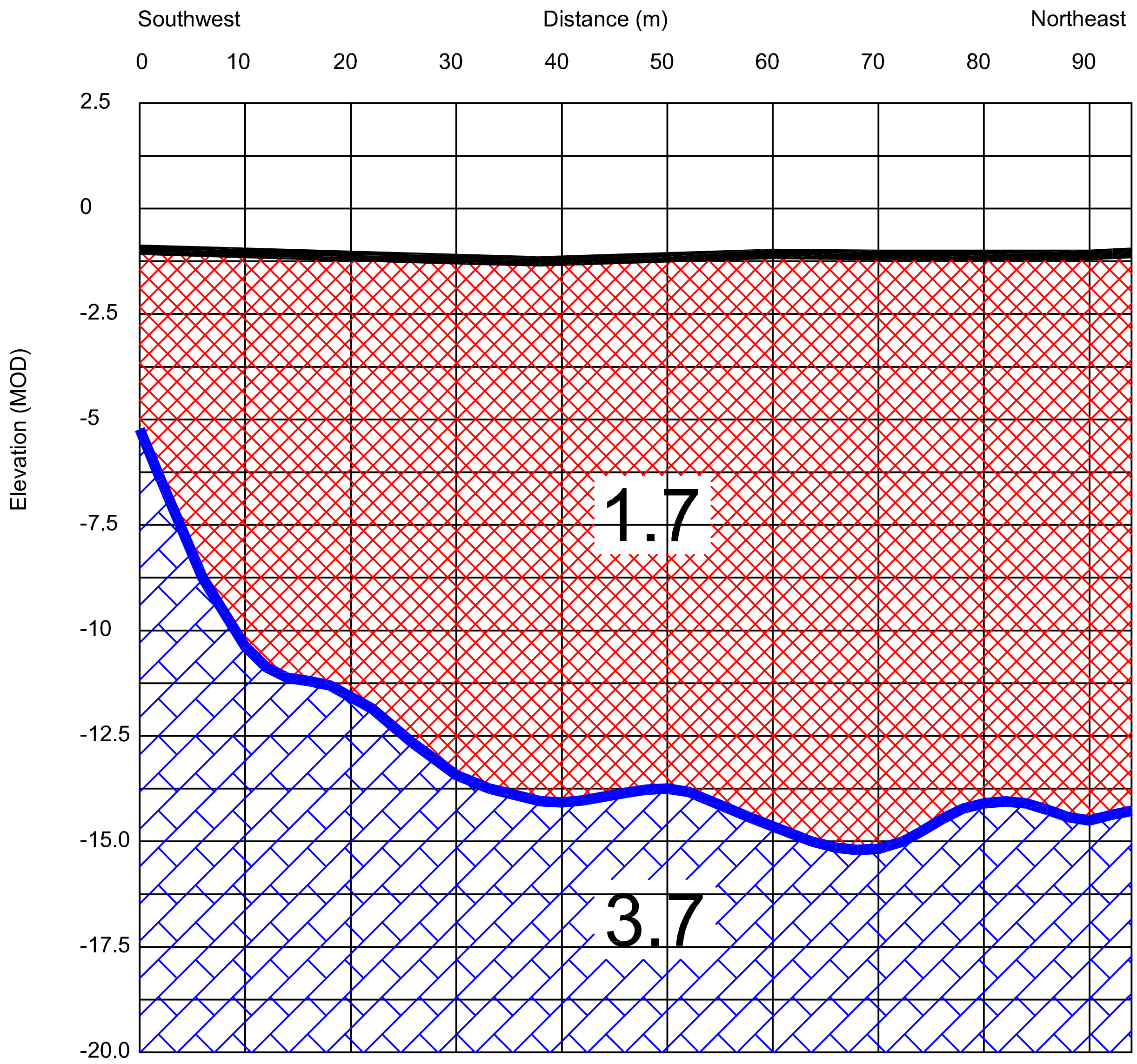

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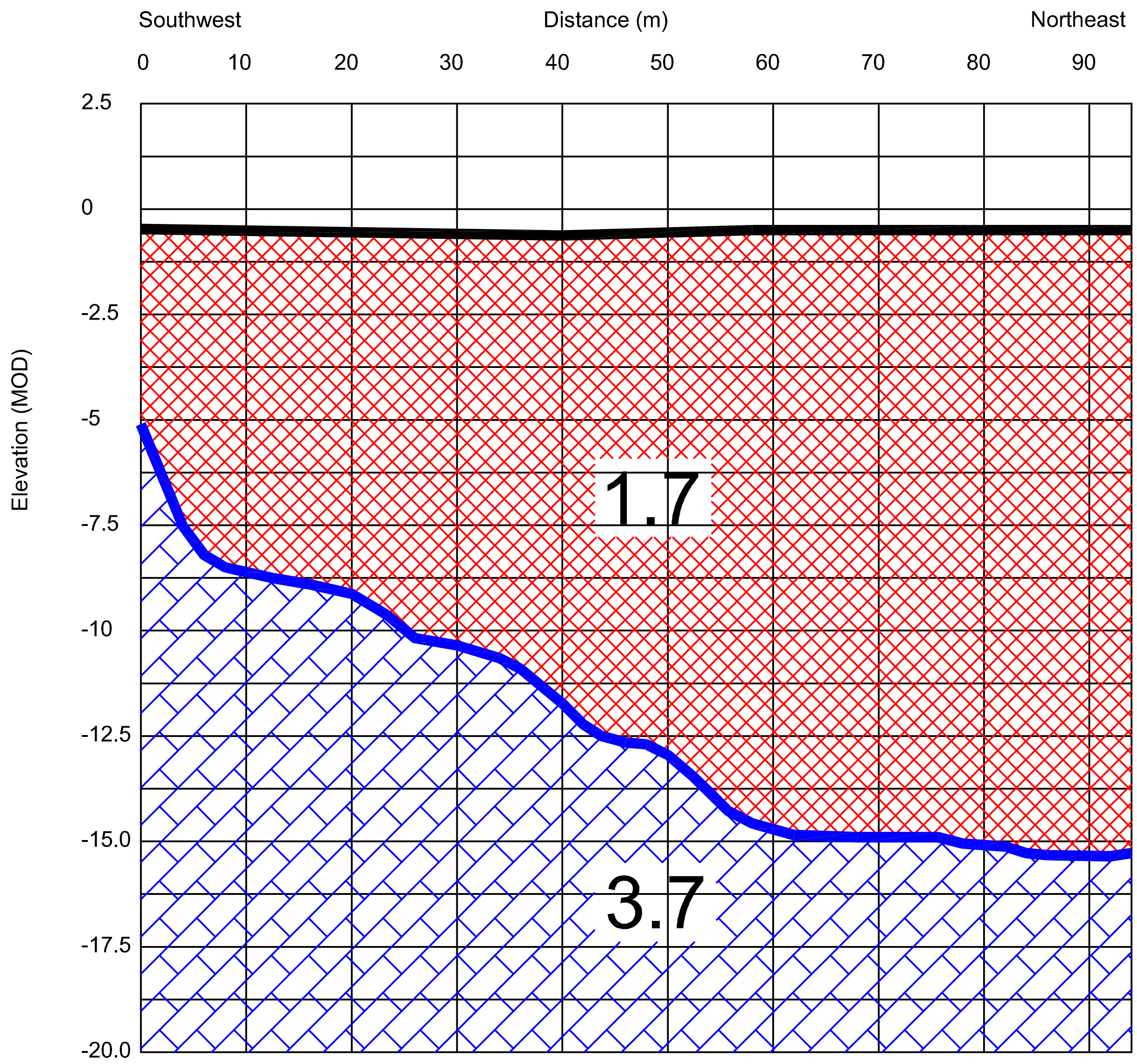
PROJECT	Belmullet Wave Energy Connection Geophysical Survey	PROJECT:	5500
		DRAWN:	TL
		DATE:	05/11/2010
TITLE	Figure 1a: Results and Interpretation of Seismic Refraction Data	MGX FILE:	5500d_Figs.dwg
		STATUS:	Draft

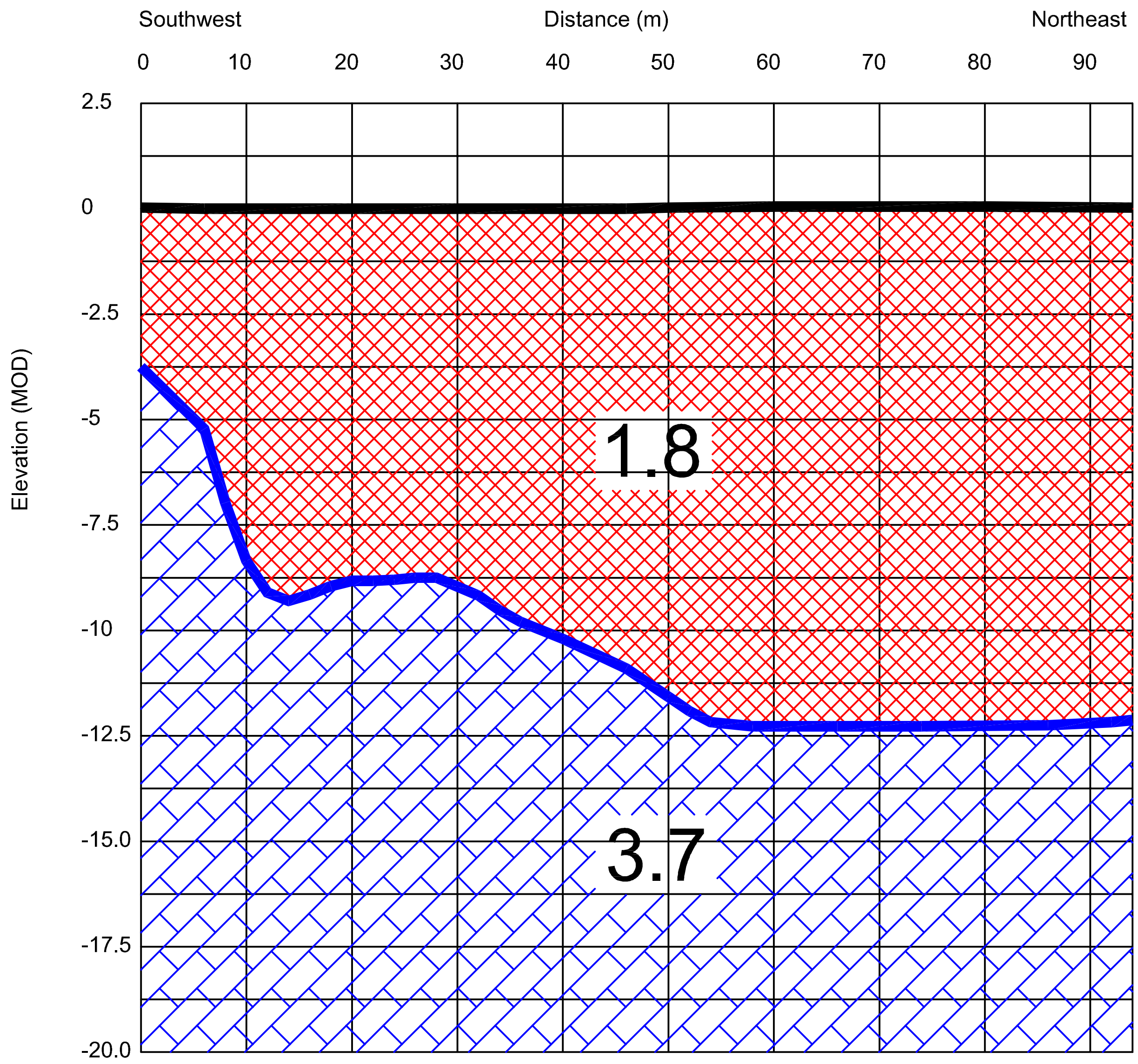
LEGEND:

- 3.7 — Seismic Velocity Km/s
- Ground Surface/Top of Layer 1 (0.6 - 0.9 Km/Sec)
- Top of Layer 2 (1.7 - 1.8 Km/Sec)
- Top of Layer 3 (3.7 - 3.8 Km/Sec)
- Soft / Loose Sand / Shingle
- Firm - Stiff / Dense Sand / Shingle (possible weathered roock at base)
- Strong Rock

Seismic Refraction Profiles S7 & S8 Model



Seismic Refraction Profiles S9 & S16 Model



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CLIENT	ESBI SEAI
PROJECT	Belmullet Wave Energy Connection Geophysical Survey
TITLE	Figure 1b: Results and Interpretation of Seismic Refraction Data

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- 3.7 — Seismic Velocity Km/s
- Ground Surface/Top of Layer 1 (0.6 - 0.9 Km/Sec)
- Top of Layer 2 (1.7 - 1.8 Km/Sec)
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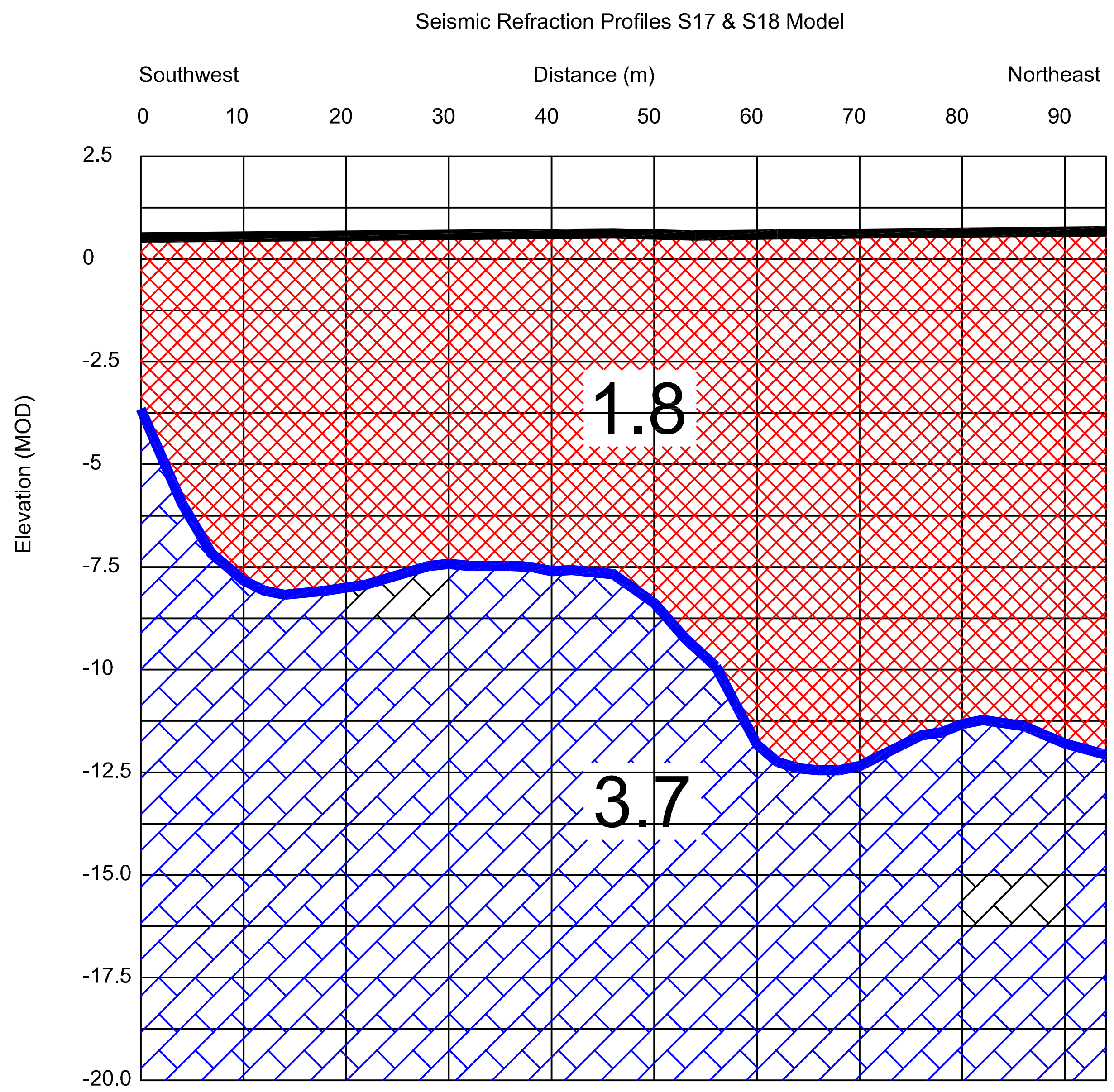
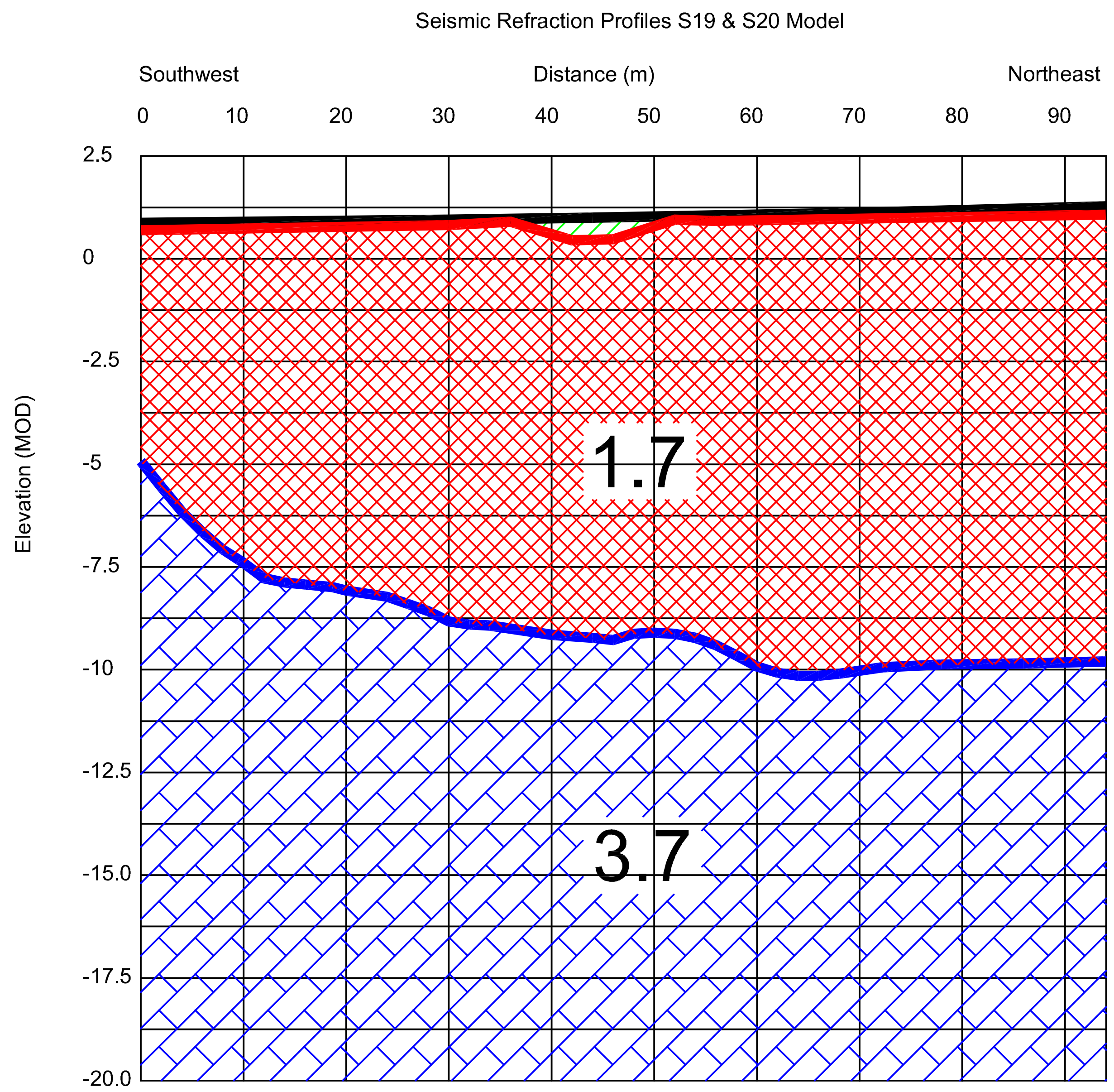
- Firm - Stiff / Dense Sand / Shingle (possible weathered roock at base)
- Strong Rock





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PROJECT: Belmullet Wave Energy Connection
Geophysical Survey

TITLE: Figure 1c: Results and Interpretation
of Seismic Refraction Data

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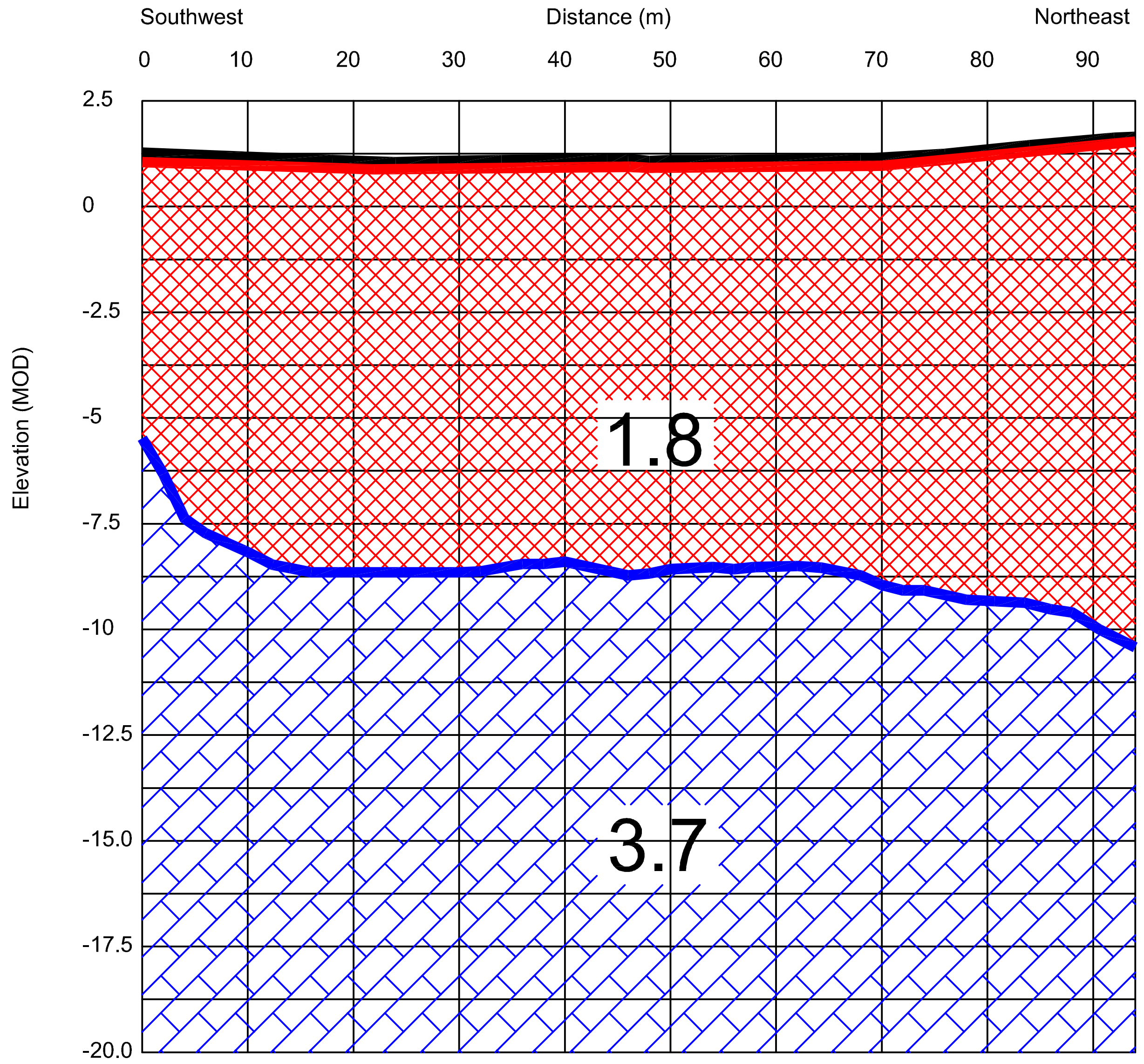
3.7 Seismic Velocity Km/s
Ground Surface/Top of Layer 1 (0.6 - 0.9 Km/Sec)
Top of Layer 2 (1.7 - 1.8 Km/Sec)
Top of Layer 3 (3.7 - 3.8 Km/Sec)
Soft / Loose Sand / Shingle
Firm - Stiff / Dense Sand / Shingle (possible weathered roock at base)
Strong Rock

Seismic Refraction Profiles S21 & S22 Model



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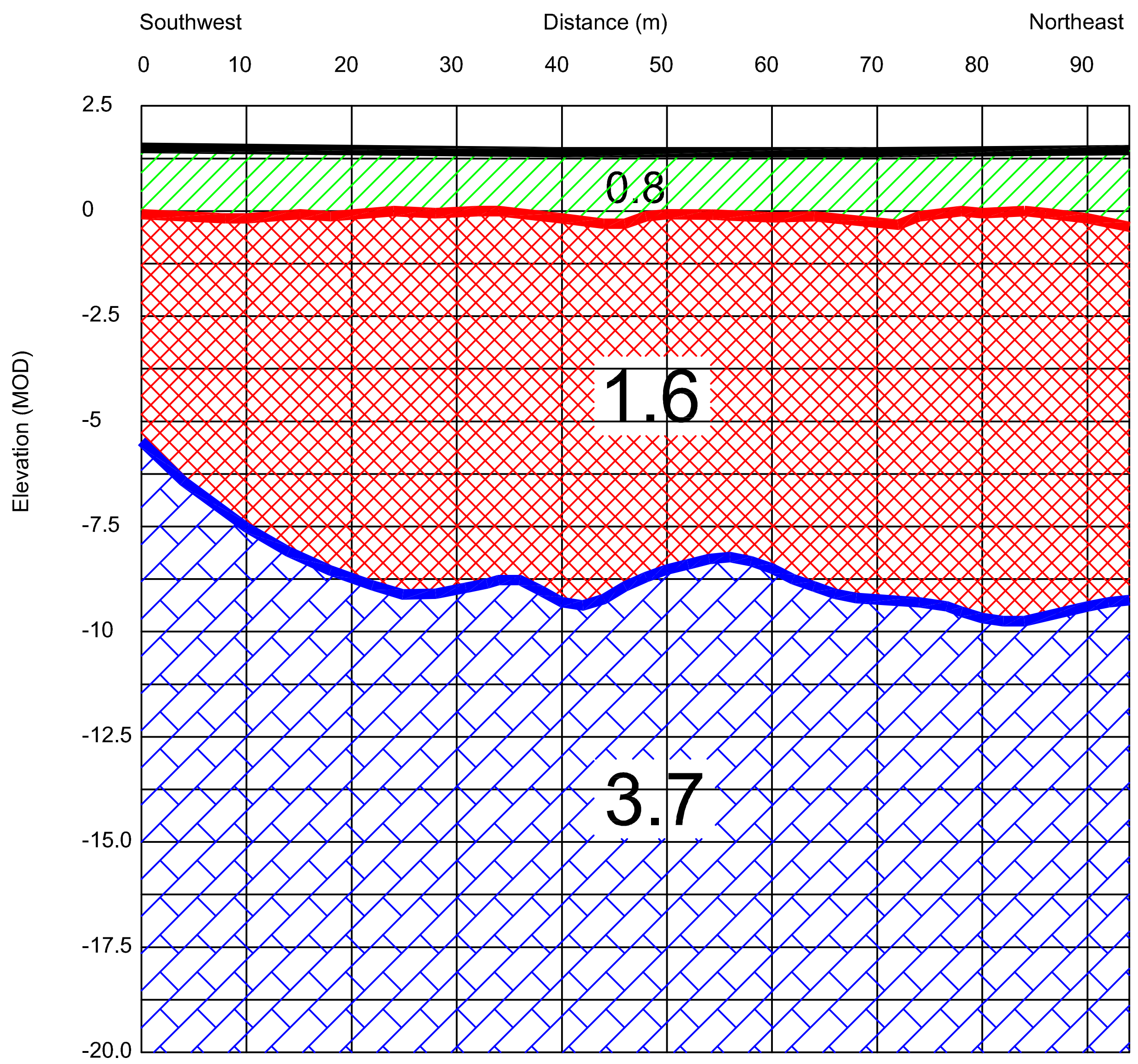

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PROJECT: Belmullet Wave Energy Connection Geophysical Survey

TITLE: Figure 1d: Results and Interpretation of Seismic Refraction Data

SCALE:	NTS, VE x 4
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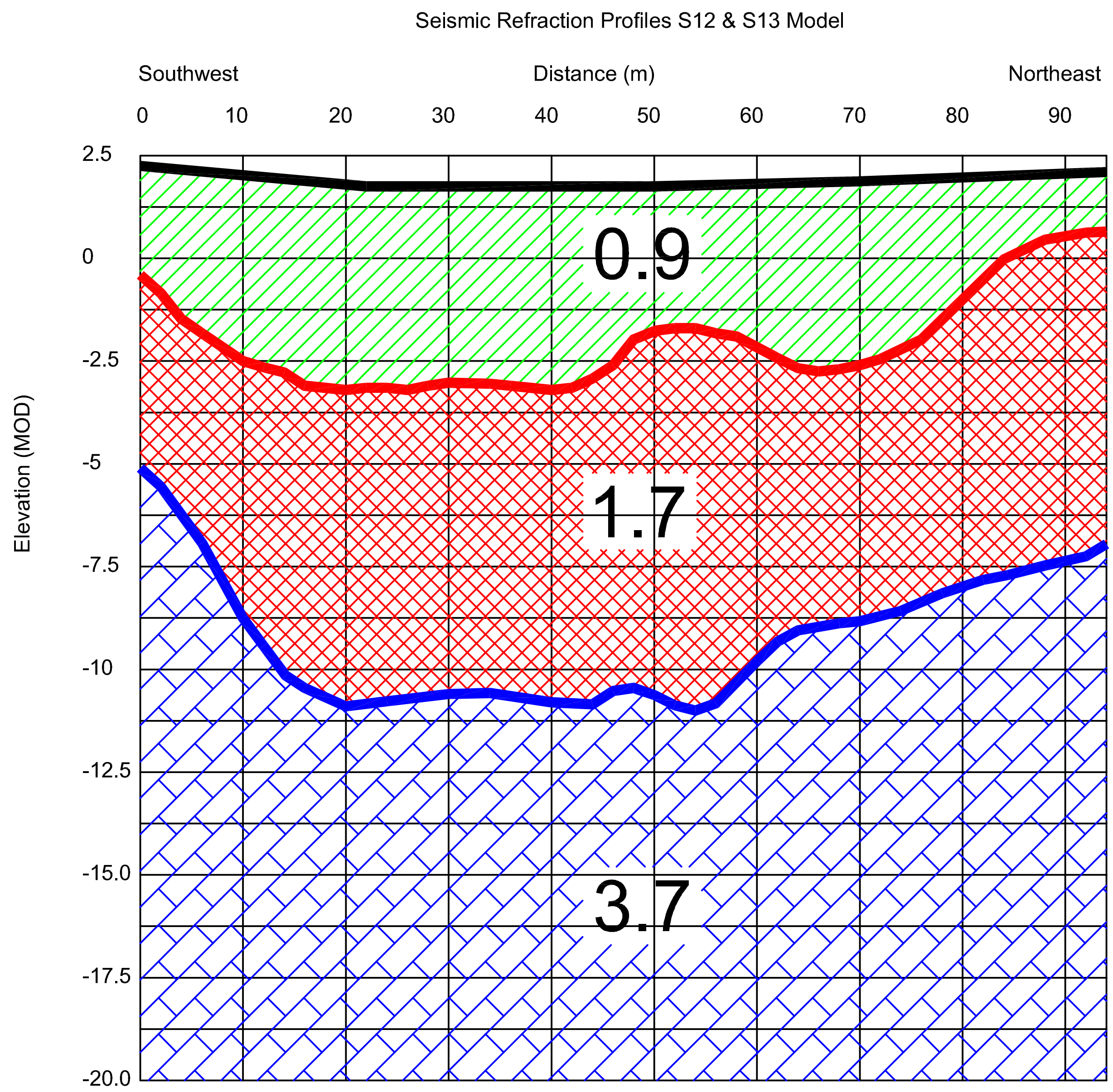

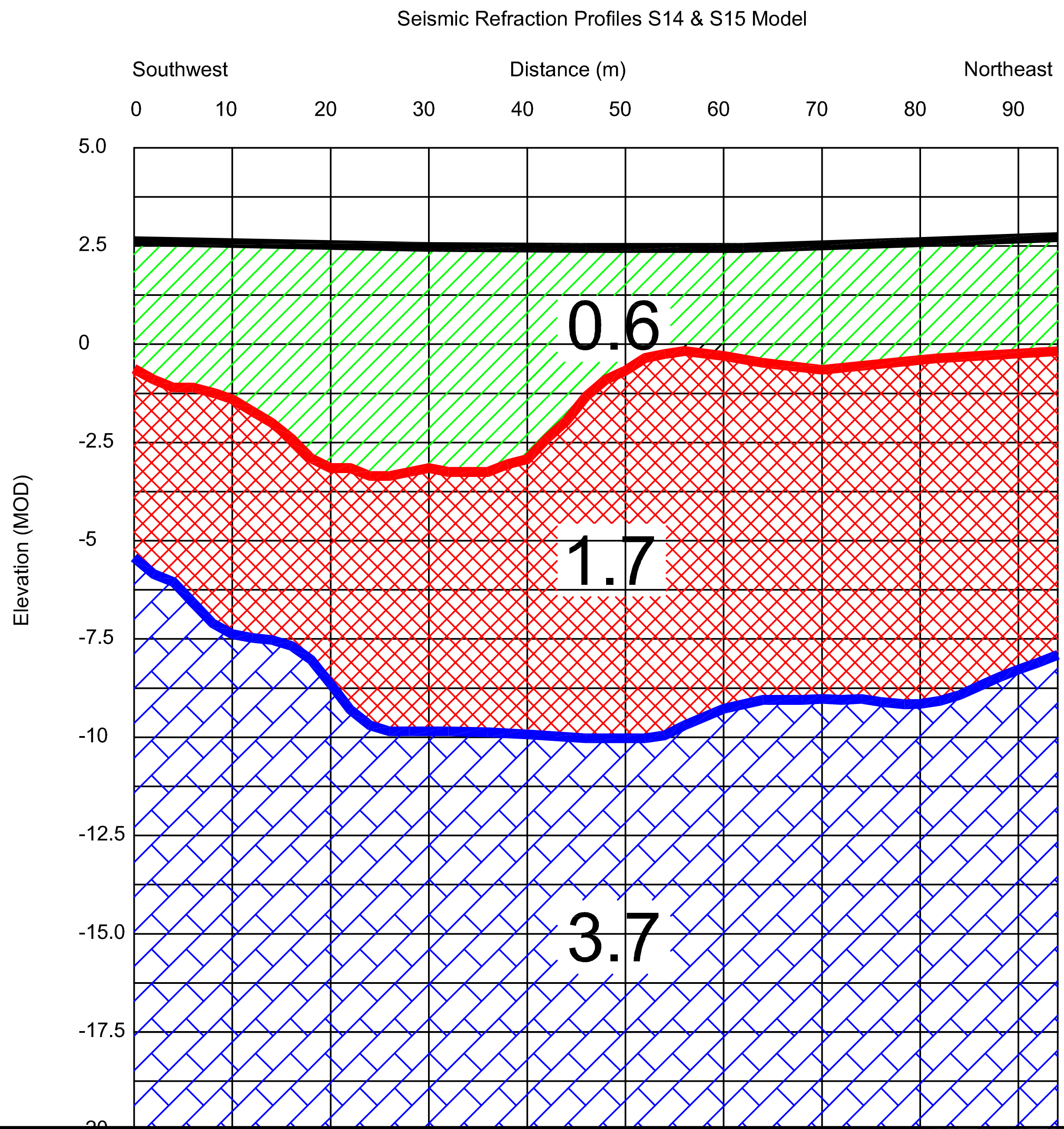

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CLIENT ESBI
SEAI

PROJECT Belmullet Wave Energy Connection
Geophysical Survey

TITLE Figure 1e: Results and Interpretation of Seismic Refraction Data

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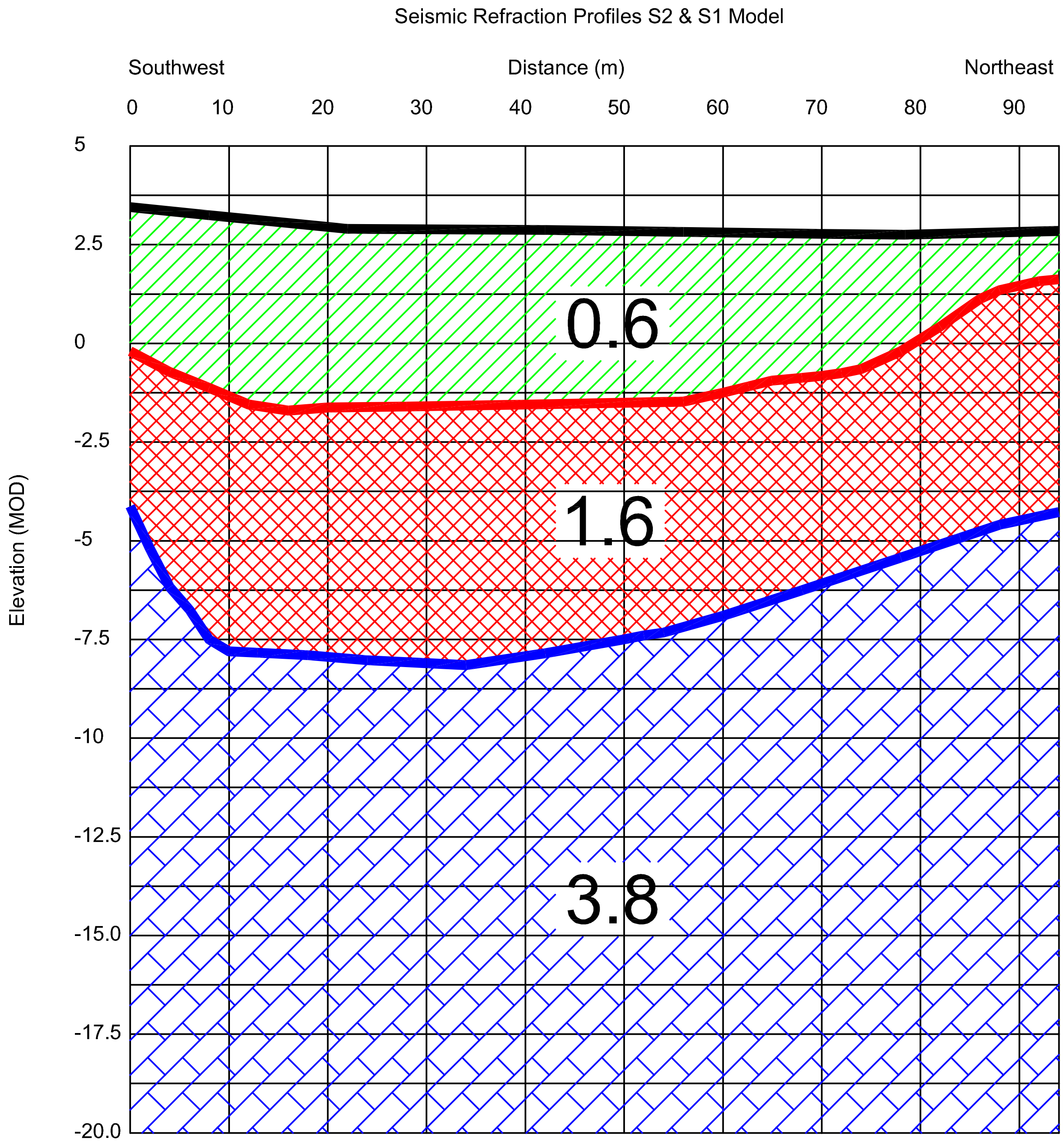
MGX FILE:	5500d_Figs.dwg
STATUS:	Draft

LEGEND:

3.7 Seismic Velocity Km/s
Ground Surface/Top of Layer 1 (0.6 - 0.9 Km/Sec)
Top of Layer 2 (1.7 - 1.8 Km/Sec)
Top of Layer 3 (3.7 - 3.8 Km/Sec)
Soft / Loose Sand / Shingle
Firm - Stiff / Dense Sand / Shingle (possible weathered roock at base)
Strong Rock



Minerex Geophysics Limited Unit F4, Maynooth Business Campus Maynooth, Co. Kildare Tel. (01) 6510030 Fax. (01) 6510033 Email: info@mgx.ie Web: www.mgx.ie	CLIENT ESBI SEAI	SCALE: NTS, VE x 4
	PROJECT Belmullet Wave Energy Connection Geophysical Survey	PROJECT: 5500
		DRAWN: TL
		DATE: 05/11/2010
	TITLE Figure 1f: Results and Interpretation of Seismic Refraction Data	MGX FILE: 5500d_Figs.dwg
		STATUS: Draft

LEGEND:

3.7	Seismic Velocity Km/s
(black line)	Ground Surface/Top of Layer 1 (0.6 - 0.9 Km/Sec)
(red line)	Top of Layer 2 (1.7 - 1.8 Km/Sec)
(blue line)	Top of Layer 3 (3.7 - 3.8 Km/Sec)
(green hatch)	Soft / Loose Sand / Shingle
(red crosshatch)	Firm - Stiff / Dense Sand / Shingle (possible weathered roock at base)
(blue hatch)	Strong Rock