GBGMAPS

Advanced Subsurface Investigations

Report

Ocean Beach Geotechnical and Geophysical Survey, Denmark WA

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1. EXECUTIVE SUMMARY

This report presents the findings of a geophysical subsurface investigation undertaken by GBG Maps Pty Ltd (GBGMAPS) for the Shire of Denmark (The Shire) in February 2019. The investigation was carried out along an approximate 600m section of coastal foreshore and dune system in Ocean Beach Western Australia.

The objective of the investigation was to provide information on the subsurface material within the investigation area, in particular to define the natural sand dune strata and underlying rock profile. The investigation was carried out as part of a key recommendation of the Ocean Beach and Peaceful Bay Coastal Hazard Risk Management and Adaptation Plan (2018). The investigation forms a jointly funded project between The Shire and Department of Transport Coastal Adaptation and Protection (CAP) grant.

As part of the investigation scope Multi-channel Analysis of Surface Wave (MASW) data was acquired along a series of pre-determined transects. Intrusive geotechnical testing was carried out at locations along the transects by way of Cone Penetrometer Testing (CPT) in order to provide ground truthing and to calibrate the geophysical results.

The acquired dataset was processed and analysed to provide contoured cross-sections showing variations in the seismic shear-wave velocity of the subsurface material. The seismic velocity sections were demarcated into velocity ranges representing different subsurface conditions and calibrated with CPT results to generate interpreted geological sections showing the modelled depth to weathered and competent limestone relative to Mean Sea Level.

The level to the interpreted top of rock profile and overlying sand thickness along the geophysical transects have been presented in map view giving an overview of the rock level and depth within the investigation area.

The results of the investigation will be used by The Shire to determine the extent and strength of underlying rock along Ocean Beach, and to understand its influence on coastal change and identify any potential risk to public safety or infrastructure assets. This understanding will inform future coastal management and planning.

2. INTRODUCTION

At the request of Shire of Denmark (The Shire), GBG Maps Pty Ltd (GBGMAPS) carried out a geophysical investigation along a 600m section of coastal foreshore and dune system at Ocean Beach Western Australia in February 2019. The investigation was carried out as part of Coastal Hazard Risk Management and Adaption Planning and forms a jointly funded project between The Shire and Department of Transport Coastal Adaptation and Protection (CAP) grant.

During the investigation, 5 geophysical transects of Multi-channel Analysis of Surface Waves (MASW) data was acquired, processed and analysed. In addition to geophysical testing, Cone Penetrometer Testing (CPT) was carried out at 10 point locations along the transects in order to provide ground truthing and to calibrate the geophysical results.

The objective of the investigation was to define the depth of rock underlying the dune system in order to understand its influence on coastal change and identify potential risk to public safety.

3. INVESTIGATION SITE

The investigation was carried out along a 600m section of coastal foreshore and dune system in Ocean Beach WA. Figure 1 shows the extent of the investigation area as a yellow dashed polygon.

Figure 1: The extent of the geophysical investigation in yellow (Aerial imagery from Landgate).

Figures 2 and 3 show the location of the site in relation to the town of Denmark and city of Perth respectively.

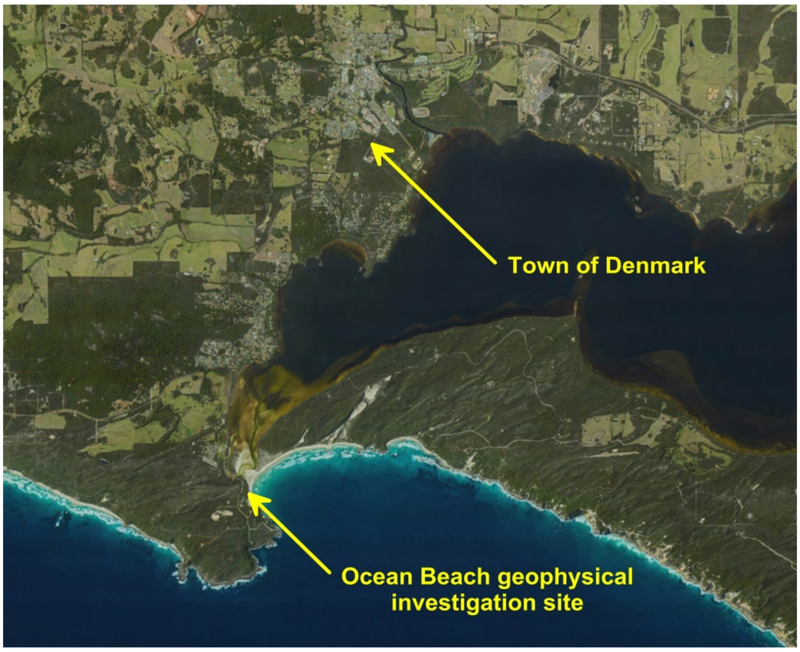


Figure 2: Ocean Beach site in relation to Denmark.

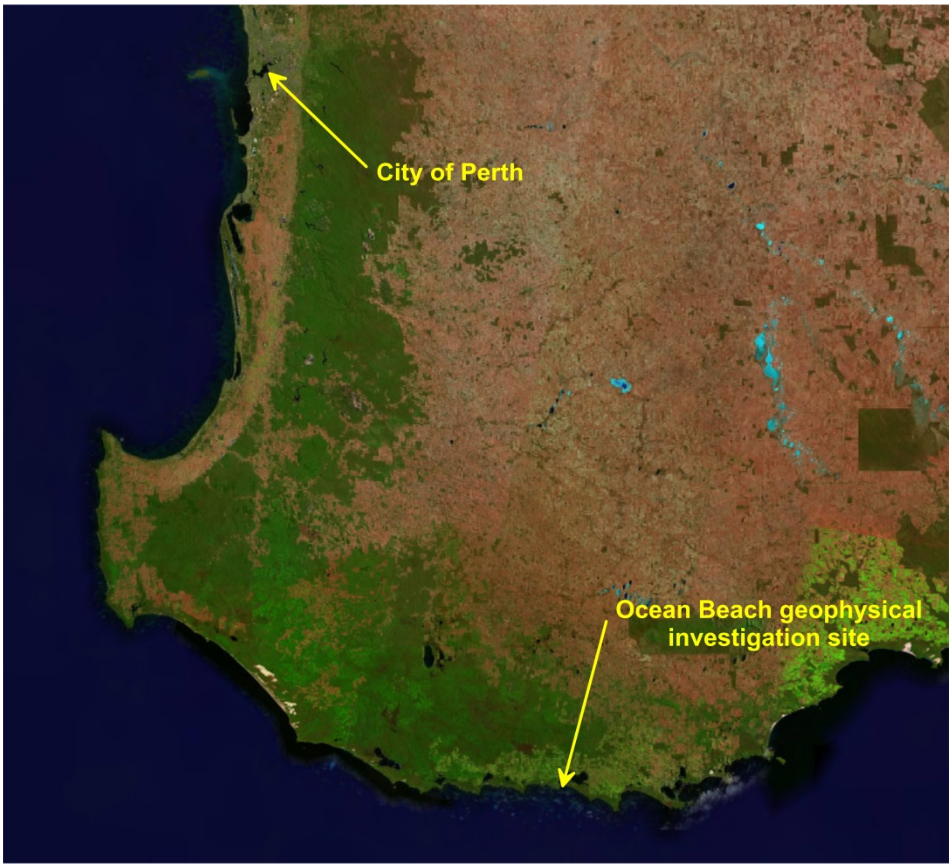


Figure 3: Ocean Beach site in relation to Perth.

Geophysical testing was carried out on the verge of Ocean Beach Road, vehicle and pedestrian paths, car parking area and the beach foreshore. Overall site conditions were suitable for the acquisition of high quality geophysical data. Photographs of the typical site conditions are show in Figure 4 below.

Figure 4: Typical site conditions along Ocean Beach Road (top left), at the entrance of the beach carpark (top right) and along the foreshore on Ocean Beach (bottom left and right).

4. SUBSURFACE TEST METHODS

During the investigation two subsurface test methods were used so as to provide the required subsurface information within the anticipated geological conditions.

- **Multi-channel Analysis of Surface Waves (MASW)**
- **Cone Penetrometer Testing (CPT)**

Refer to Appendix A for more details on the MASW method used during the investigation including theory and application.

4.1 MULTI-CHANNEL ANALYSIS OF SURFACE WAVES

MASW utilises seismic surface wave phase and frequency information to calculate shear wave (S-wave) velocities of the subsurface material. S-wave velocity is one of the elastic constants and closely related to Young's Modulus. Under most circumstances it is a direct indicator of the ground strength (stiffness) and as such the method can be used to provide quantitative results on the compaction of the subsurface material.

MASW data was acquired for transects where surface conditions were suitable including sections of asphalt road pavement and the beach foreshore. The MASW data was inverted to obtain seismic S-wave velocity models of the subsurface.

4.2 CONE PENETROMETER TESTING

CPT is a geotechnical test method for evaluating the geotechnical engineering properties of soils and assessing subsurface stratigraphy. The method involves pushing a calibrated cone and rod into the ground with a measured force. The friction resistance experienced along the cone is measured verses depth and can provide approximate compaction rates of the subsurface material as well as the refusal depth indicating the depth to competent rock.

CPT data was acquired at locations along the geophysical transects in order to provide ground truthing on the depth to competent rock and to calibrate the geophysical results.

5 DATA ACQUISITION

The geophysical site work was carried out over 3 days from 11 to 13 February 2019. Geophysical data acquisition was carried out by a two person crew from GBGMAPS consisting of qualified Geophysicists. Cone Penetrometer Testing was carried out by Probedrill Geotechnical Survey on the 13 and 14 February 2019 under the direction of GBGMAPS. Topographic survey of the geophysical transects and CPT locations was carried out by GBGMAPS concurrently with the geophysical data acquisition.

Pedestrian and traffic management was provided by The Shire during the site work where required.

During the investigation data long five (5) MASW transects totalling 1489m of profiling and ten (10) CPT points were acquired. The locations and extents of the MASW and CPT were determined after consultation with The Shire and the Department of Transport.

Details on the MASW transects and CPT points are given in Tables 1 and 2 respectively. Drawing 70488-01 in Appendix B presents the locations of the MASW transect and CPT points overlaid onto aerial imagery of the site.

Table 1 – Acquired MASW Transects

Transect	Location	Start		End		Length
		Easting	Northing	Easting	Northing	
MASW-1	Ocean Beach	530177.2	6123527.8	530095.1	6124036.1	530
MASW-2	Ocean Beach Lookout	529916.7	6124038.9	530053.8	6123995.9	192
MASW-3	Footpath	529999.1	6123699.4	530156.7	6123525.6	240
MASW-4	Beach access road	529992.1	6123596.6	530125.6	6123558.6	144
MASW-5	Ocean Beach Road	529968.8	6123623.6	530028.7	6123984.0	383

Table 2 – Cone Penetrometer Test Points

CPT ID	Coordinate (MGA 50)		Geophysical Transect
	Easting	Northing	
CPT-01	529976.3	6124048.8	MASW-2
CPT-02	530031.7	6124054.5	MASW-2
CPT-03	530039.2	6123969.2	MASW-5
CPT-04	529968.8	6123623.6	MASW-5
CPT-05	530065.6	6123661.0	MASW-3
CPT-06	530156.7	6123525.6	MASW-3
CPT-07	530162.7	6123606.3	MASW-1
CPT-08	530168.3	6123754.4	MASW-1
CPT-09	530162.0	6123919.9	MASW-1
CPT-10	530134.7	6123975.3	MASW-1

5.1 MULTI-CHANNEL ANALYSIS OF SURFACE WAVES

MASW data was acquired using an Ambrogeo Seismograph and 24 channel seismic land streamer with sledgehammer source. Acquisition parameters are provided in Table 1.

Table 3 – MASW acquisition parameters

Number of geophones	24
Geophone spacing	1 m
Geophone frequency	4.5 Hz
Array length	23 m
Record length	2 s
Sample interval	0.500 ms
Source offset	6 m
Source stacks	5
Sounding interval	6 m

MASW data acquisition involved laying out the geophone array in a straight line with its centre at the required sounding location. Seismic data was recorded 6m outside the geophone spread, with multiple source impacts being stacked in order to enhance the seismic signal and suppress noise. Data was recorded during dulls in background noise such as in the absence of vehicles and pedestrians to reduce the effects of background noise on the data. The geophone array was then towed by a 4WD 6m along the profile with the process repeated until the end of the transect was reached. A photograph of MASW data acquisition is shown in Figure 5.

Figure 5: MASW data acquisition along Ocean Beach.

5.2 CONE PENETROMETER TESTING

CPT was carried out using a 12 tonne, Marooka M1 CPT rig. Testing was carried out until refusal was reached with tip resistance of typically between 40 and 80MPa. A photograph of CPT is shown in Figure 6.

Figure 6: CPT carried out during a previous coastal investigation by GBGMAPS.

5.3 SPATIAL POSITIONING

Spatial positioning was achieved using a Navcon DGPS receiver providing <100mm accuracy both vertically and horizontally. Corrections were achieved using Continuously Operating Reference Stations (CORS) from the Albany bench mark.

Easting and Northing positions are given in GDA94 (MGA zone 50), whilst elevations are given in Australian Height Datum (mAHD).

6 GEOPHYSICAL DATA QUALITY AND PROCESSING

6.1 MULTI-CHANNEL ANALYSIS OF SURFACE WAVES

The MASW data was observed to be of high quality with the seismic records having high signal to noise ratio. The generated overtone images plotting phase velocity against frequency showed a prominent dispersion curve of the surface wave component.

The MASW data was processed using SurfSeis V4 (Kansas Geological Survey, 2014) with the following inversion routine used:

1. Overtone images giving the percentage intensity of phase velocity versus frequency were generated for each acquired seismic record.
2. The maximum intensity across the useful range of frequencies was picked for each record resulting in a dispersion curve (Figure 7).
3. The dispersion curves were then run through a 20 layer inversion algorithm to produce an S-wave velocity soundings.
4. Adjacent S-wave velocity soundings along the transects were compiled and gridded using Surfer V13 (Golden Software, 2016) in order to generate S-wave velocity sections showing variations in the modelled S-wave velocity laterally along the transects and with elevation.

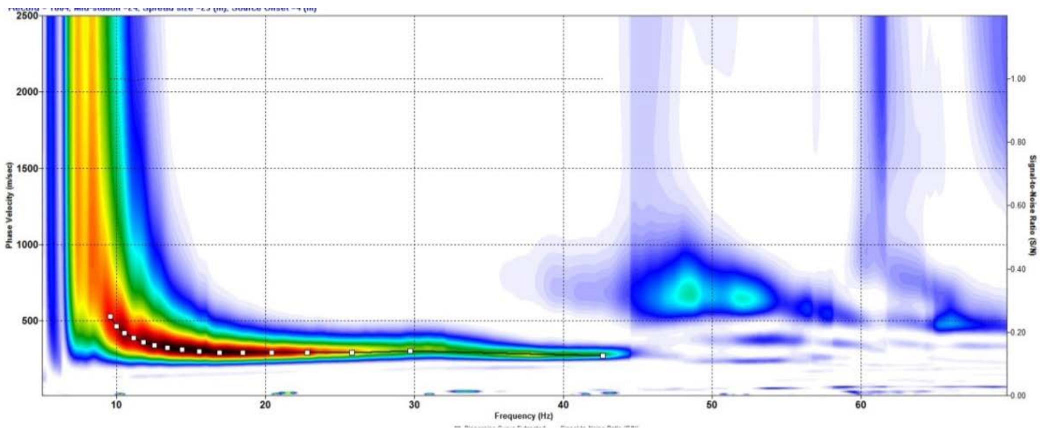


Figure 7: MASW overtone image with high signal to noise ratio and picked dispersion curve.

6.2 SEISMIC WAVE PROPAGATION

Seismic S-wave velocity is governed by the elastic properties of the medium that the wave propagates through as shown in the equation below. As such calculated seismic S-wave velocity can provide a useful guide to the subsurface material condition with increasing velocity an indication of increasing material hardness and stiffness.

Seismic S-wave velocity $$V_s = \sqrt{\frac{G}{\rho}}$$

where; G = Shear modulus, ρ = In-situ material density

7 RESULTS AND INTERPRETATION

7.1 PRESENTATION OF RESULTS

The results of the Ocean Beach Geotechnical and Geophysical Survey carried out as part of Coastal Hazard Risk Management and Adaption Planning by the Shire of Denmark are provided in Appendices B and C of this report as follows:

Appendix B – MASW Velocity Sections and Geological Interpretation

- **70488-01**. Site map showing acquired geophysical transects and CPT locations.
- **70488-02**. Line 01 Shear-wave velocity section and interpretation (CH 0-360m).
- **70488-03**. Line 01 Shear-wave velocity section and interpretation (CH 360-530m).
- **70488-04.** Line 02 Shear-wave velocity section and interpretation.
- **70488-05.** Line 03 Shear-wave velocity section interpretation.
- **70488-06.** Line 04 Shear-wave velocity section interpretation.
- **70488-07.** Line 05 Shear-wave velocity section interpretation.
- **70488-08.** Site map with modelled level (mAHD) to top of interpreted rock

Appendix C – Cone Penetrometer Test Plots

- Electric Friction Cone Penetrometer plots – CPT locations 1 to 10
- CPT calibration certificate

7.2 GEOPHYSICAL AND INTERPRETED CROSS SECTIONS

The results of the geophysical transects are presented as drawings in Appendix B. At the top of each drawing is the seismic S-wave velocity section generated from the MASW data. The images show the variations in the seismic s-wave velocity as a contour plot as per the colour scale with increasing velocity from blue, green, yellow, orange, red then brown. The subsurface s-wave velocity ranges are 150m/s to 600m/s.

Below the seismic velocity section is a geological section giving the interpreted layering of the subsurface based on detectable seismic velocity contrasts. These have been correlated with the CPT data which are shown as black rectangles overlayed onto the sections. The calculated seismic velocity values have been classed into four categories representing different subsurface conditions:

1. **Very low seismic wave velocity** (Vs <300m/s). Regions with very low seismic wave velocity are interpreted as sand of low compaction.

2. **Low seismic wave velocity** (Vs 300-350m/s). Regions with low seismic wave velocity are interpreted as moderately compacted sand with possible lithified sand or calcarenite lenses.

3. **Moderate seismic wave velocity** (Vs 350-450m/s). Regions with moderate seismic wave velocity are interpreted as extremely weathered to weathered limestone with low rock strength. It is likely that this class represents a highly variable weathered limestone and transitional zone to stronger, more competent limestone below.

4. **Moderate to high seismic wave velocity** (Vs >450m/s). Regions with moderate to high seismic wave velocity are interpreted as limestone of low to moderate rock strength. It is postulated that this class represents competent or slightly weathered limestone.

7.3 CONE PENETROMETER TESTING

The results of the CPTs are presented in Appendix C showing the plots of cone tip resistance in mega-pascal against depth in metres. The CPT plots are also shown in Appendices B below the interpreted geological sections for calibration of the geophysical transects.

The CPTs returned a tip resistance at refusal ranging from between 40MPa and 80MPa indicating moderately weathered to competent rock. The depths below the existing ground level to refusal ranged from 0.80m at CPT08 to 8.4m at CPT06.

It was observed that CPTs 01, 06, 09 and 10 had a highly variable tip resistance prior to refusal. It is postulated that this represents inconsistent zones of variably weathered limestone where the CPT pushed into low strength limestone before meeting refusal at harder competent limestone. These areas may relate to karst features such as voiding or soft limestone.

7.4 CORRELATION OF SUBSURFACE TEST METHODS

The depth to competent limestone interpreted from the CPT data generally shows good correlation with that obtained from the S-wave velocity sections. The following observations have been made:

- Strong correlation was observed between the MASW and CPT datasets where there was a sudden increase in tip resistance then refusal in the CPT logs such as for CPTs 2, 3, 4, 5, 7 and 8. In such cases the subsurface material is likely to consist of sands of low to moderate compaction overlying competent limestone (Figure 8, left).

- Weaker correlation was observed where the CPT logs exhibited highly variable tip resistance prior to refusal such as for CPTs 1, 6, 9 and 10. In such cases the subsurface material is likely to consist of sands overlying variable strength limestone with possible intermittent sand lenses and with deeper competent limestone (Figure 8, right).

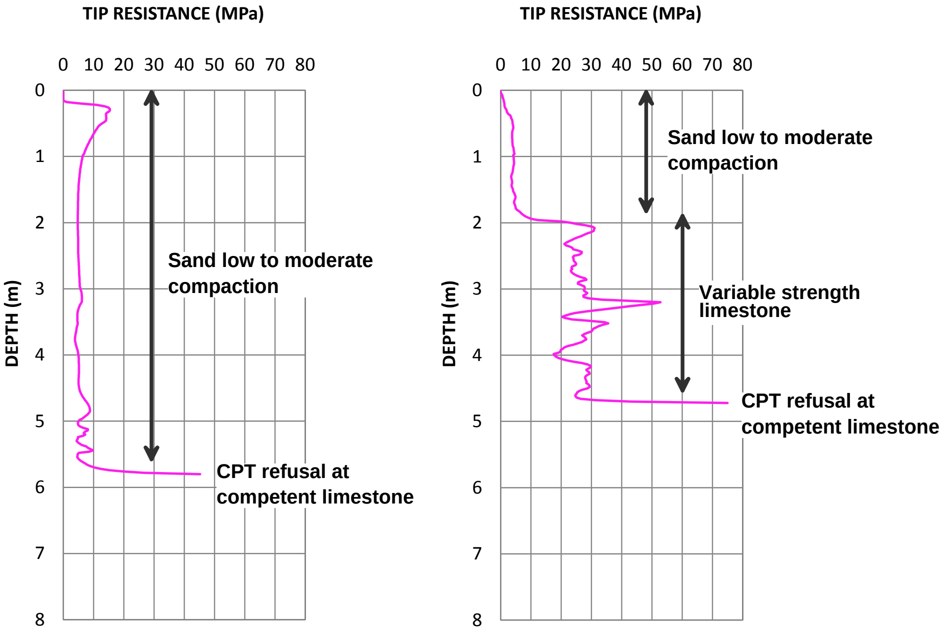


Figure 8: Tip resistance plots for CPT 3 (left) and CPT 10 (right).

The differences in the depth to weathered and competent limestone as interpreted from the geophysical transects and from the CPT data can be attributed to the fact that the geophysical methods used are broad scale whilst the CPT is a point method. Geophysical methods sample a volume of subsurface material with the calculated depths at any particular point representing an average value over this volume. The CPT method samples the subsurface directly below the probe and is effected by local variations in the subsurface such as rock floaters, highly weathered zones or lenses of indurated sediment. The differences in the type of subsurface sampling of the methods will not adversely affect the results as the CPT results have been used to constrain the geophysics interpretation and as such the results represent the best modelled fit between the datasets.

7.5 MODELLED LEVEL TO TOP OF ROCK

The level to the interpreted top of rock profile and overlying sand thickness along the geophysical transects are presented in Drawings 70488-08 and 70488-09 respectively. These has been generated by digitising the interface between the natural sand dune strata and the underlying rock profile as modelled from the 5 transects and calibrated to the CPT plots.

The resulting x = Easting, y = Northing, and z = mAHD values for the top of rock have been shown as a classed post map giving the level to top of rock as eight classes from less than -5.0mAHD to greater than 10.0mAHD at 2.5m increments. The modelled sand thickness was generated by subtracting this from the surface elevation and plotted into eight classes from less than 2.0m to greater than 14.0m at 2.0m increments.

8 CONCLUSIONS

A geophysical investigation and intrusive geotechnical testing has been carried out by GBGMAPS along an approximate 600m section of coastal forehsshore and dune system at Ocean Beach, Denmark Western Australia. The investigation was carried out as part of the Coastal Hazard Risk Management and Adaptation Planning commissioned by the Shire of Denmark and in partnership with the Department of Transport Coastal Adaptation and Protection (CAP) grant.

The objective of the investigation was to provide information on the subsurface material within the investigation area, in particular to model the interface between the sand strata and underlying rock. The results of the investigation will be used by The Shire to assess the influence of the underlying rock on coastal change, and to identify potential risk to public safety or infrastructure assets.

As part of the investigation scope, Multi-channel Analysis of Surface Waves Profiling and Cone Penetrometer Testing was carried out along a series of pre-determined transects and points. The acquired MASW dataset was processed and analysed to provide cross sections showing variations in the seismic wave velocity of the subsurface material. The seismic velocity sections were demarcated into velocity ranges representing different subsurface conditions and correlated with the CPT plots to generate geological sections showing the modelled level to top of weathered and competent limestone relative to mAHD.

The level to the modelled top of rock profile and overlying sand thickness along the geophysical transects have been presented in map view giving an overview of the rock level and depth within the investigation area.

The methods used during the investigation are geophysical and as such the results are based on indirect measurements and the processing and interpretation of seismic wave signals with limited calibration. The findings in this report represent the best professional opinions of the authors, based on experience gained during previous similar investigations and with correlation to known and assumed subsurface ground conditions at the site.

We trust that this report and the attached drawings provide you with the information required. If you require clarification on any points arising from this geophysical investigation, please do not hesitate to contact the undersigned or Andrew Spyrou on (08) 6436 1599.

For and on behalf of
GBGMAPS PTY LTD

BAQIR AL ASADI

Geophysicist

APPENDIX A.
GEOPHYSICAL METHODS

MULTI-CHANNEL ANALYSIS OF SURFACE WAVES

GBGMAPS
Advanced Subsurface Investigations

APPLICATIONS

- ✓ Bedrock mapping
- ✓ Degree of sediment compaction
- ✓ Determination of geotechnical parameters (e.g. shear modulus)
- ✓ Void detection
- ✓ Liquefaction potential
- ✓ Subsurface profiling
- ✓ Imaging velocity inversions (hard layer overlying softer layer)

METHOD

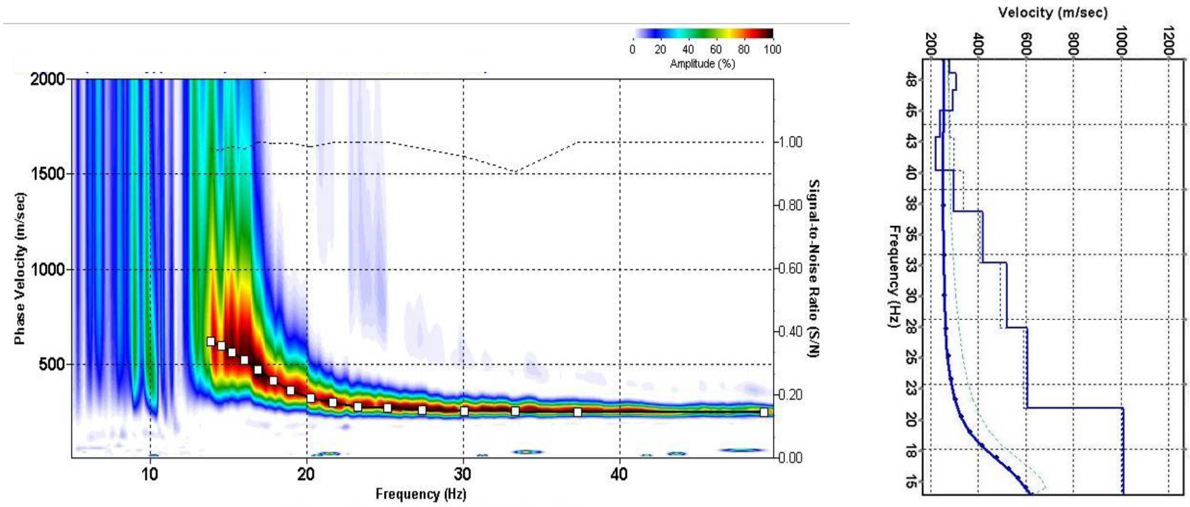
The Multi-channel Analysis of Surface Waves method (MASW) is a non-destructive seismic method which uses the elastic properties of subsurface materials to determine subsurface structure. By analysis of the dispersive properties of varying frequencies from a single seismic source, shear-wave velocity (Vs) and associated geotechnical parameters can be determined.

MASW uses an active seismic source such as a hammer or weight drop impact to produce seismic energy consisting predominantly of Pressure (P-) waves and Shear (S-) waves. MASW uses the S-wave dispersion component to provide information on the shear velocity to a depth determined by frequency range of the energy source and array configuration.

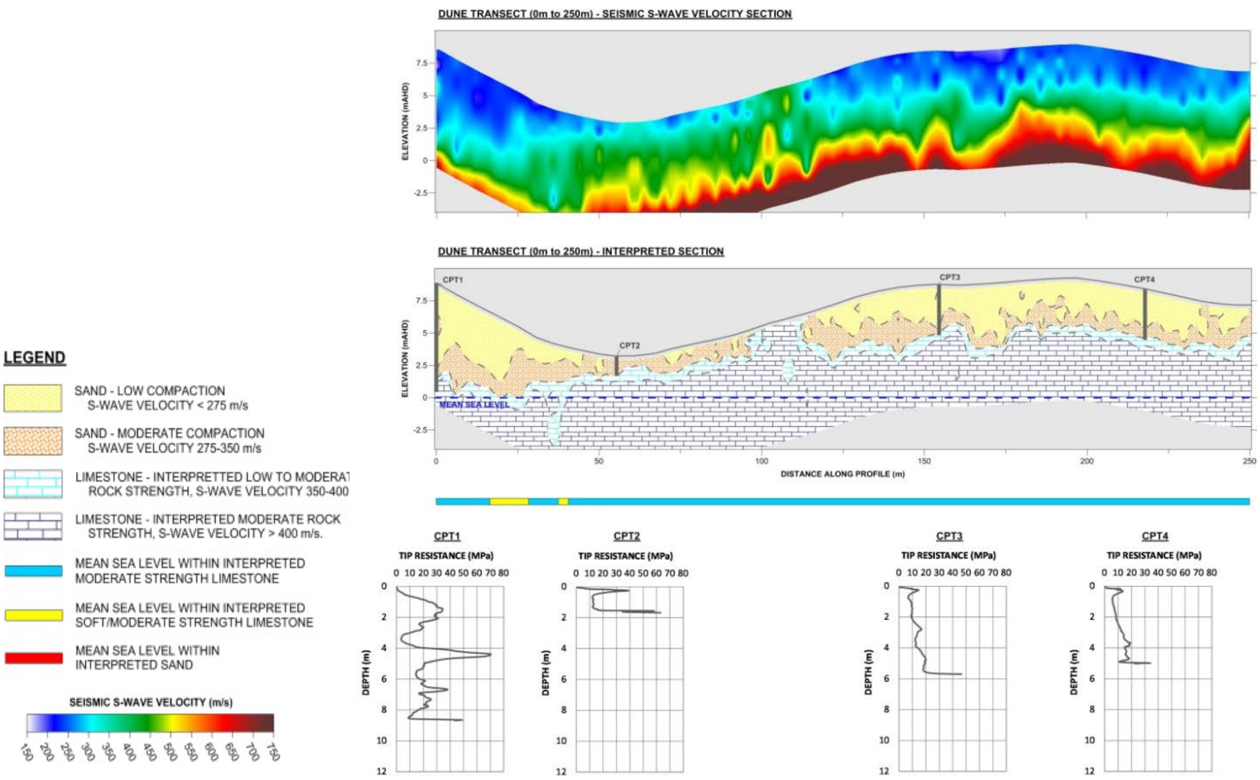
Seismic surface waves have dispersion properties that traditionally utilized body waves lack. Differing wavelengths/frequencies have different depth of penetration, and therefore propagates with different phase velocity, with an increase in wavelength being proportional to increased depth of penetration. As the surface wave is the dominant wave generated from any seismic source, MASW data quality (signal to noise) tends to be higher than other seismic methods such as seismic reflection or refraction.

DATA ANALYSIS & PRESENTATION

Analysis of the collected MASW seismic records is concentrated on the S-wave dispersion component. Dispersion curves are extracted for each collected record from the overtone image showing the percentage intensity of phase velocity versus frequency. These curves are then inverted to produce 1D S-wave soundings typically to a depth of up to 30 m. The calculated 1D soundings can then be compiled and gridded to produce 2D sections showing the variation in S-wave velocity both laterally along the profile and with depth.



Dispersion curve generated from an MASW sounding (left image), modelled S-wave velocity sounding generated from inversion of the picked dispersion curve

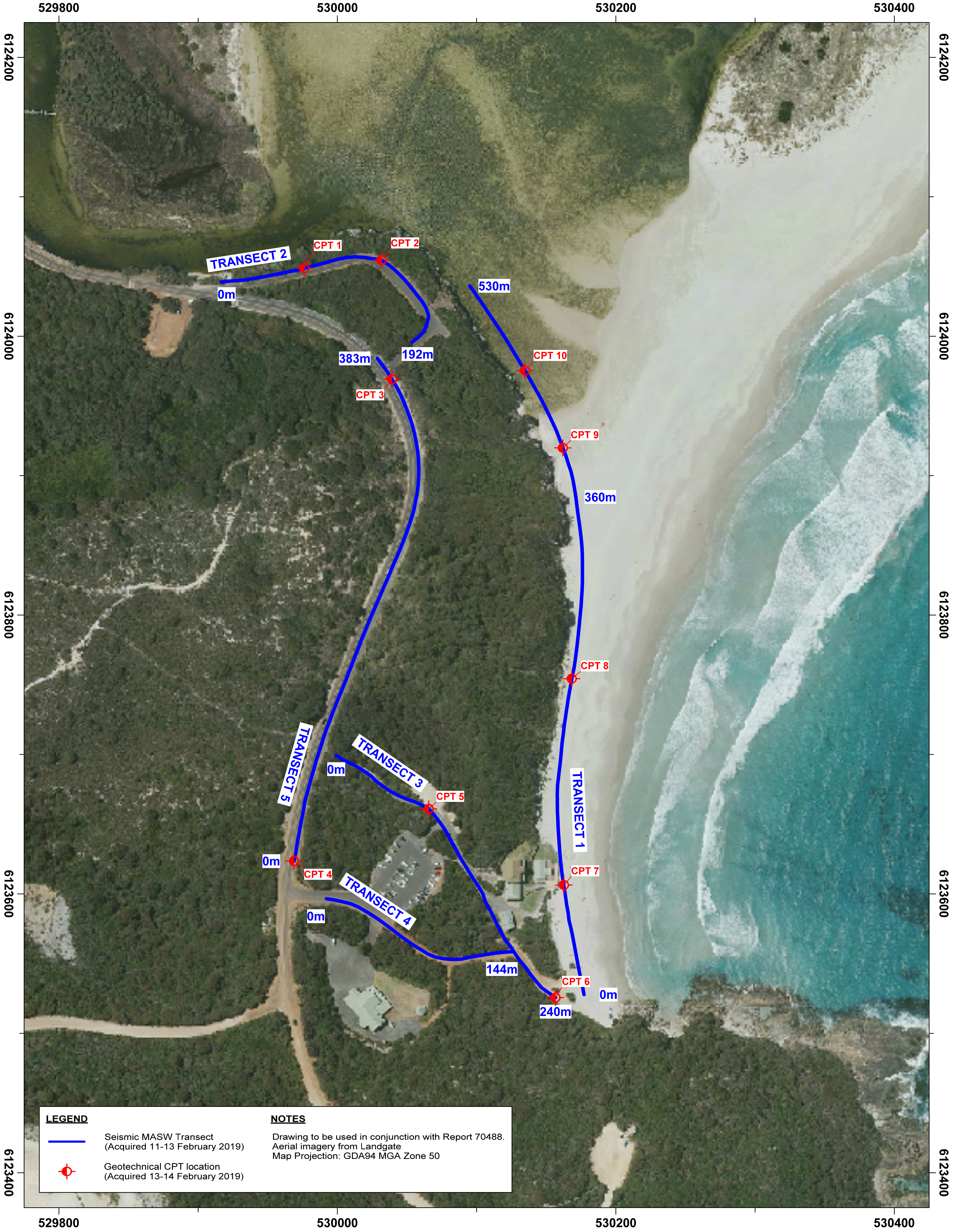


MASW seismic S-wave 2D velocity section with interpretation.

APPENDIX B.
INVESTIGATION RESULTS

OCEAN BEACH GEOTECHNICAL AND GEOPHYSICAL SURVEY - DENMARK WESTERN AUSTRALIA

SITE PLAN WITH SEISMIC TRANSECTS AND GEOTECHNICAL TEST POINTS



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Drawing	70488-01	Revision	0	

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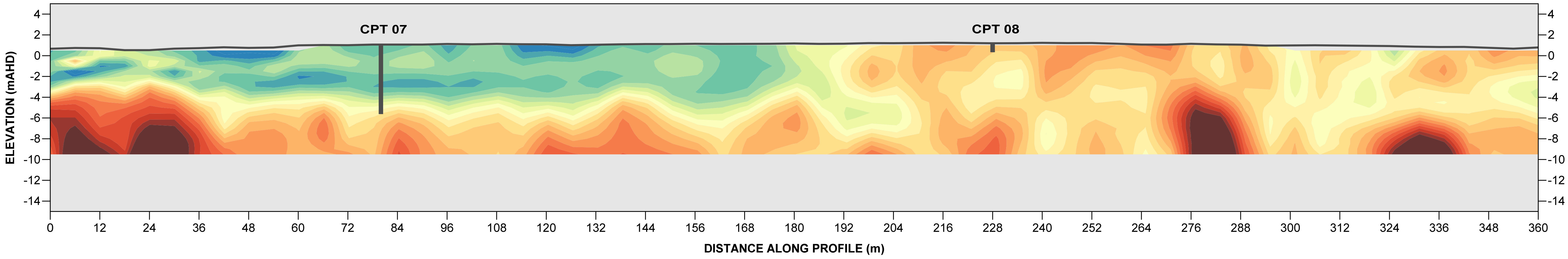
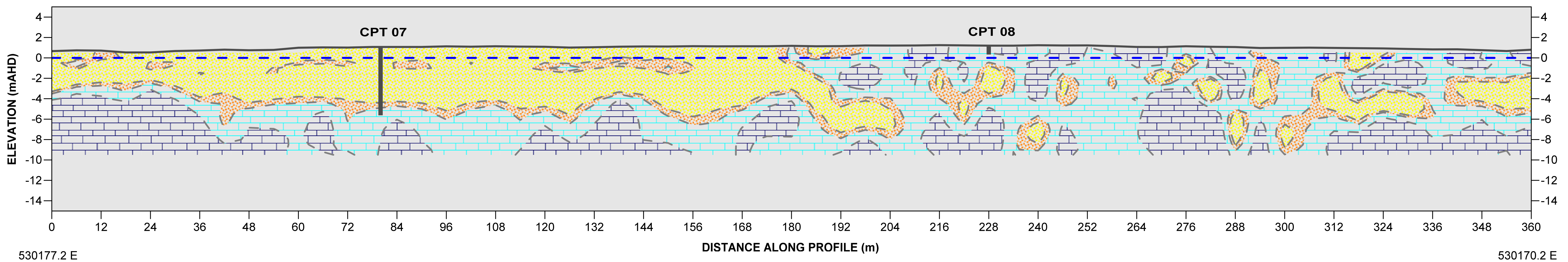
OCEAN BEACH GEOTECHNICAL AND GEOPHYSICAL SURVEY - DENMARK WESTERN AUSTRALIA

TRANSECT - 1 (0 - 360m)

SEISMIC S-WAVE VELOCITY SECTION



GEOLOGICAL INTERPRETED SECTION



530177.2 E
6123527.8 N

530170.2 E
6123890.9 N

LEGEND

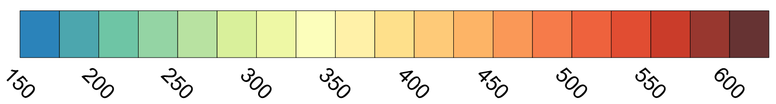
SAND - LOW COMPACTION
S-WAVE VELOCITY < 300 m/s

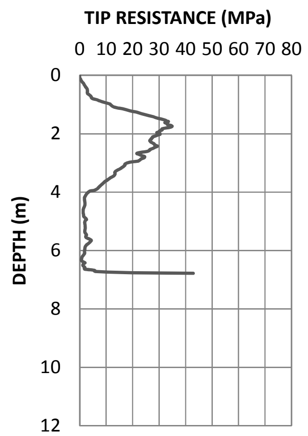
SAND MODERATE COMPACTION WITH POSSIBLE LITHIFIED SAND/CALCARENITE LENSES
S-WAVE VELOCITY 300-350 m/s

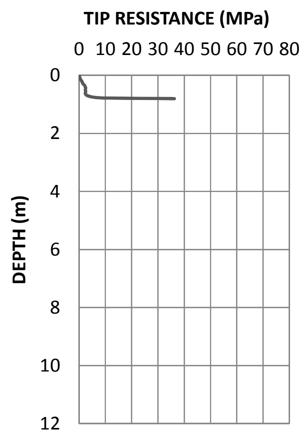
0mAHD

LIMESTONE - EXTREMELY WEATHERED TO WEATHERED
LOW ROCK STRENGTH, S-WAVE VELOCITY 350-450 m/s.

LIMESTONE - WEATHERED TO COMPETENT
LOW TO MODERATE ROCK STRENGTH. S-WAVE VELOCITY > 450 m/s.







NOTES

Map Projection GDA 94, MGA Zone 50.
Elevation in Australian Height Datum (mAHD)
Refer to Drawing 70488-01 for transect location.
Drawing to be used in conjunction with Report 70488.

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	Drawing	70488-02	Revision	0

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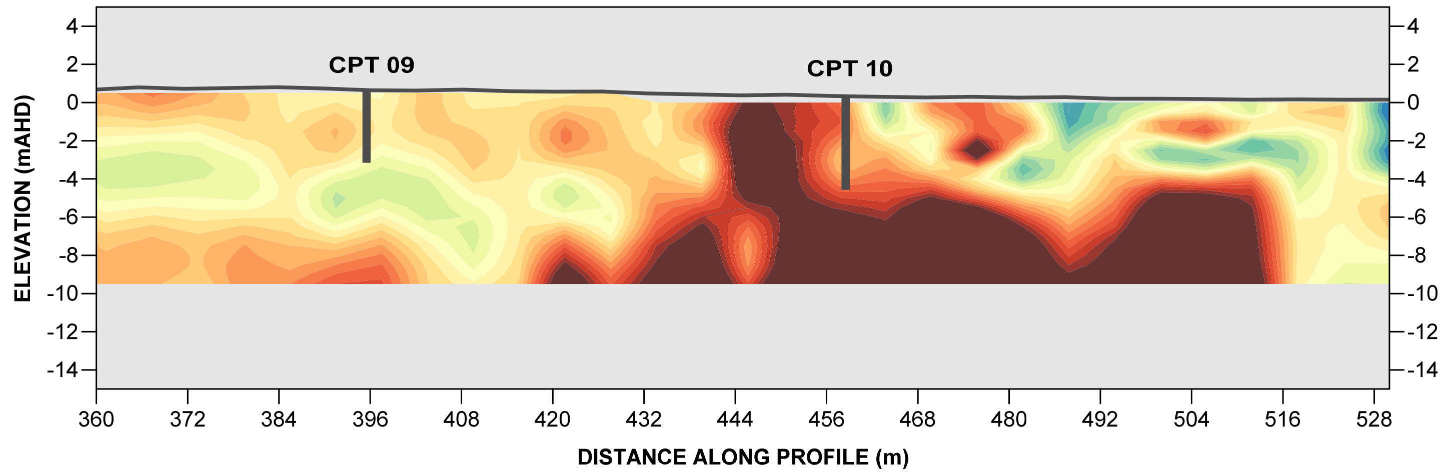
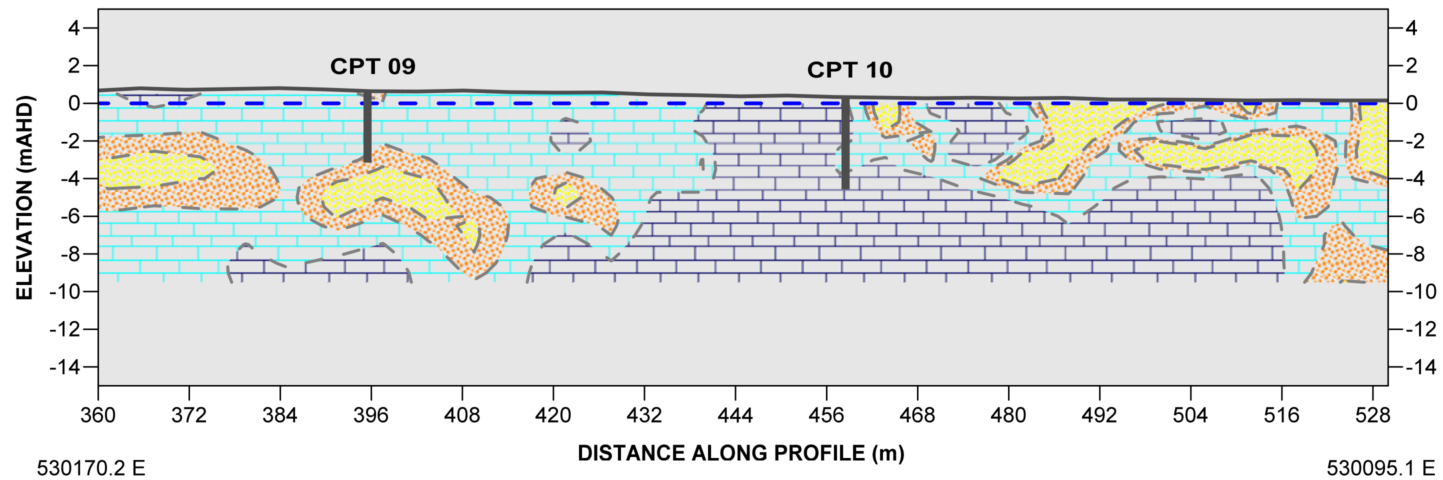
OCEAN BEACH GEOTECHNICAL AND GEOPHYSICAL SURVEY - DENMARK WESTERN AUSTRALIA

TRANSECT - 1 (360 - 530m)

SEISMIC S-WAVE VELOCITY SECTION

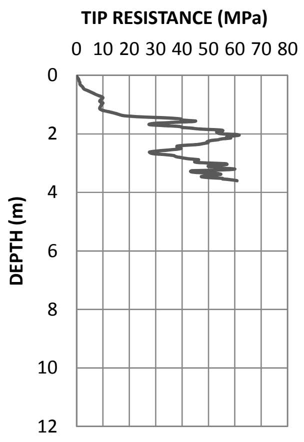


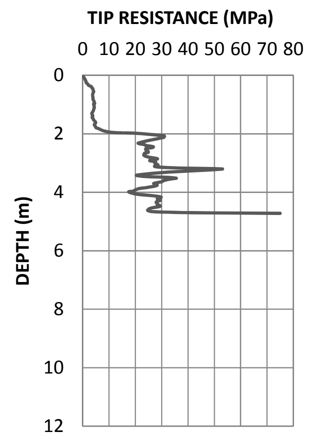
GEOLOGICAL INTERPRETED SECTION



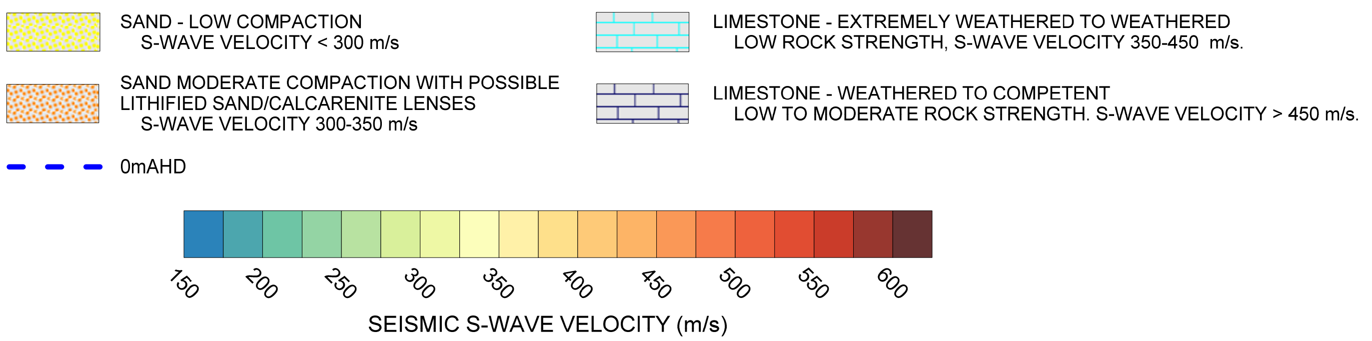
530170.2 E
6123890.9 N

530095.1 E
6124036.1 N





LEGEND



NOTES
Map Projection GDA 94, MGA Zone 50.
Elevation in Australian Height Datum (mAHD)
Refer to Drawing 70488-01 for transect location.
Drawing to be used in conjunction with Report 70488.

CLIENT	SHIRE OF DENMARK				
	OCEAN BEACH GEOTECHNICAL AND GEOPHYSICAL SURVEY DENMARK WESTERN AUSTRALIA	Date	18 February 2019	Paper Size	A3
		Scale	1:400 Ver, 1:1000 Hor	Drawn	TAL
		Drawing	70488-03	Revision	0

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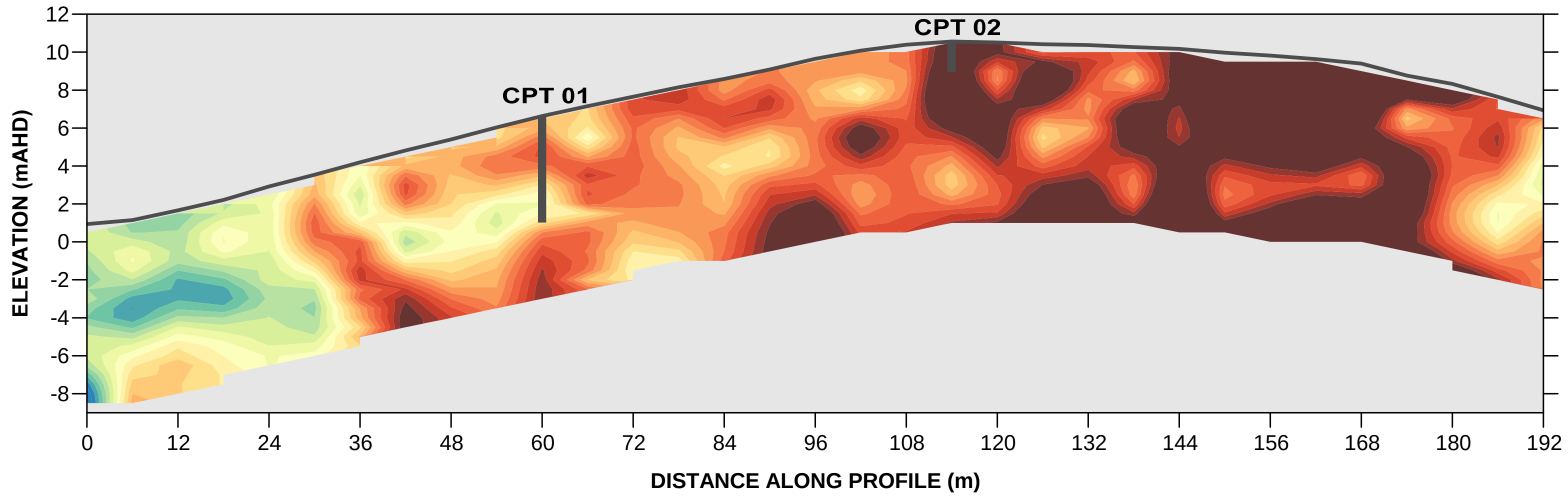
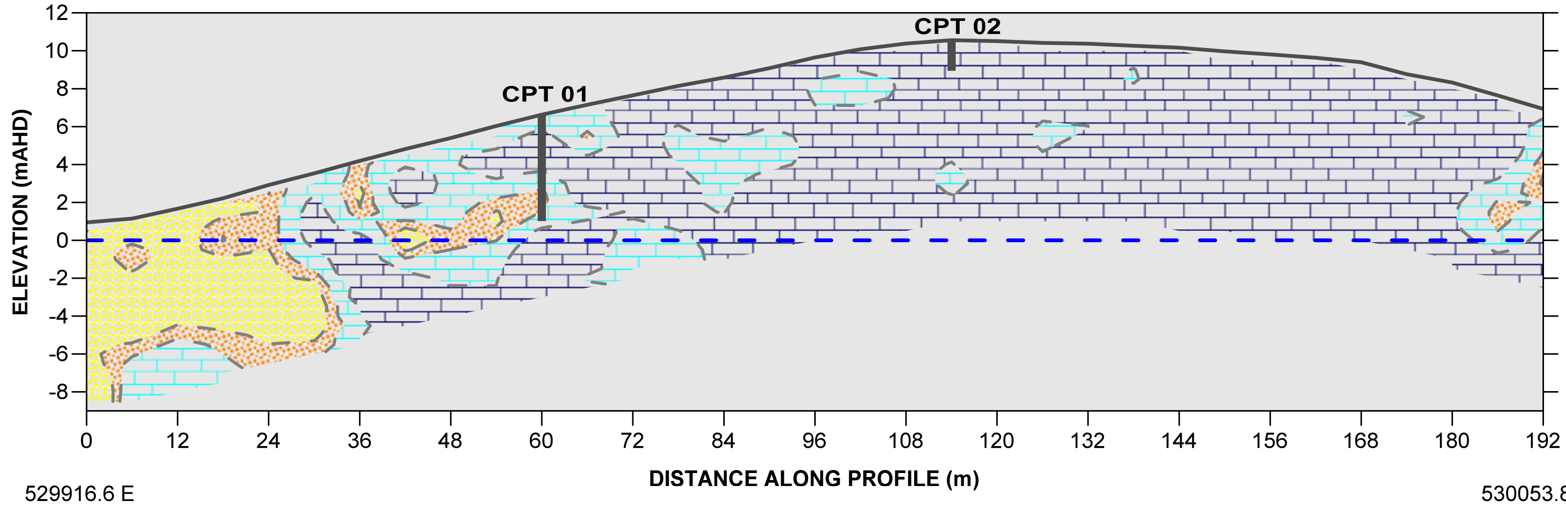
OCEAN BEACH GEOTECHNICAL AND GEOPHYSICAL SURVEY - DENMARK WESTERN AUSTRALIA

TRANSECT - 2

SEISMIC S-WAVE VELOCITY SECTION



GEOLOGICAL INTERPRETED SECTION



529916.6 E
6124038.9 N

530053.8 E
6123995.9 N

LEGEND

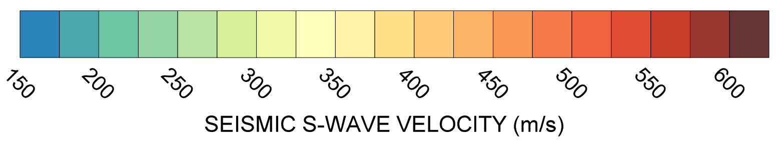
SAND - LOW COMPACTION
S-WAVE VELOCITY < 300 m/s

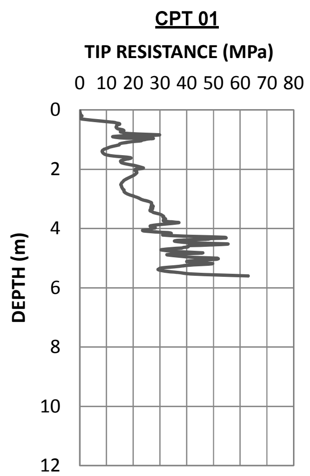
SAND MODERATE COMPACTION WITH POSSIBLE LITHIFIED SAND/CALCARENITE LENSES
S-WAVE VELOCITY 300-350 m/s

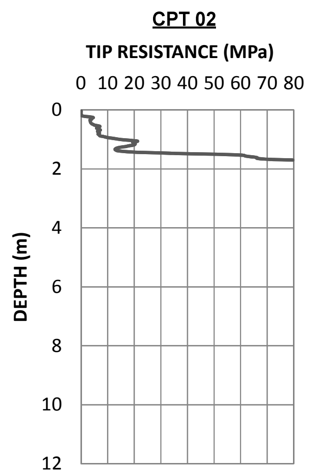
LIMESTONE - EXTREMELY WEATHERED TO WEATHERED
LOW ROCK STRENGTH, S-WAVE VELOCITY 350-450 m/s.

LIMESTONE - WEATHERED TO COMPETENT
LOW TO MODERATE ROCK STRENGTH. S-WAVE VELOCITY > 450 m/s.

0mAHD







NOTES
Map Projection GDA 94, MGA Zone 50.
Elevation in Australian Height Datum (mAHD)
Refer to Drawing 70488-01 for transect location.
Drawing to be used in conjunction with Report 70488.

CLIENT **SHIRE OF DENMARK**	Date 18 February 2019	Paper Size A3	GBGMAPS Advanced Subsurface Investigations
OCEAN BEACH GEOTECHNICAL AND GEOPHYSICAL SURVEY DENMARK WESTERN AUSTRALIA	Scale 1:400 Ver, 1:1000 Hor	Drawn TAL	
	Drawing 70488-04	Revision 0	

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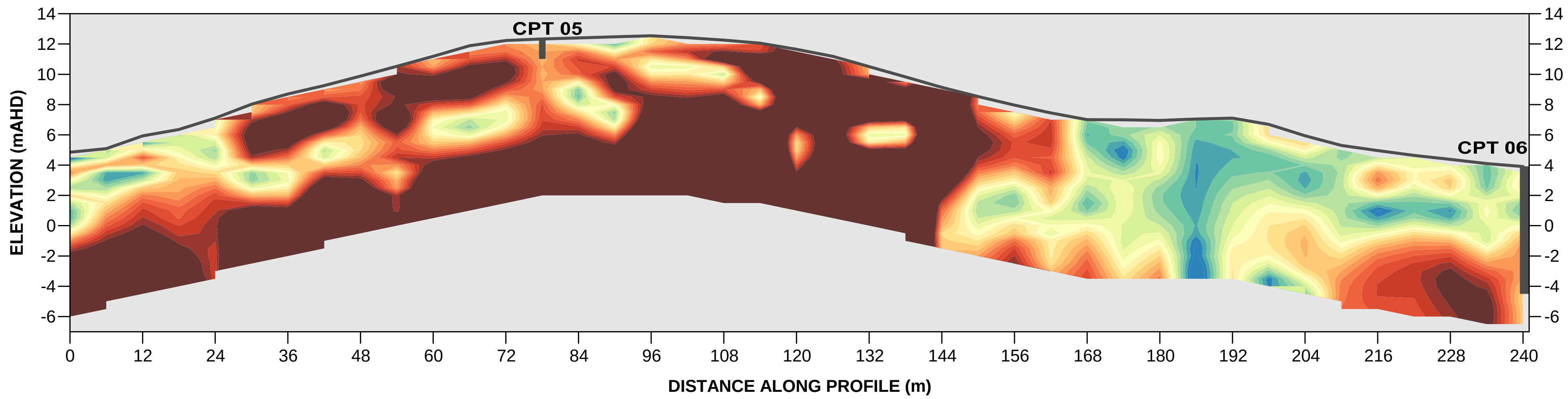
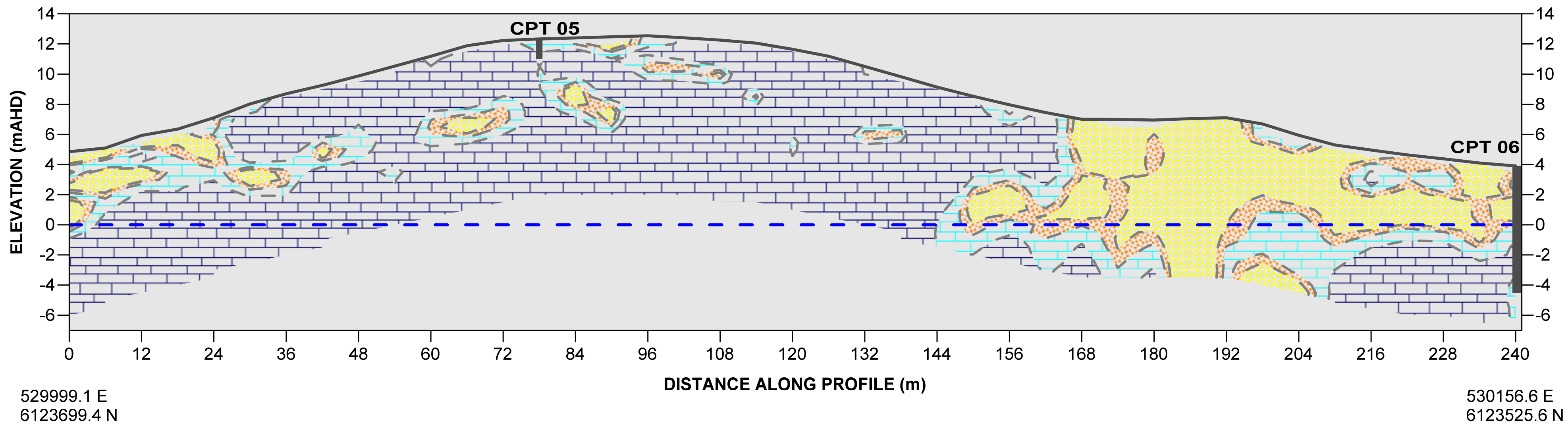
OCEAN BEACH GEOTECHNICAL AND GEOPHYSICAL SURVEY - DENMARK WESTERN AUSTRALIA

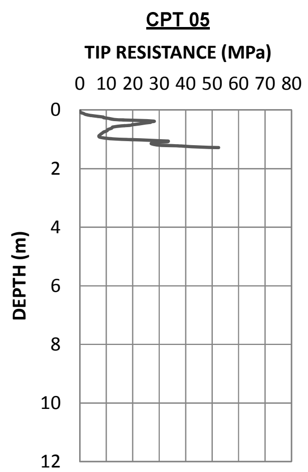
TRANSECT - 3

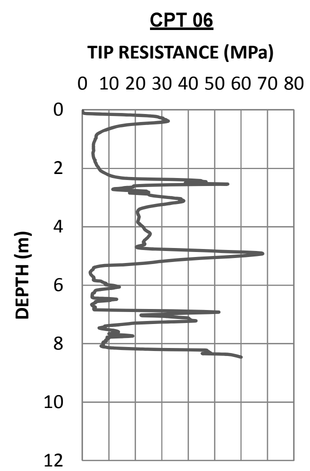
SEISMIC S-WAVE VELOCITY SECTION



GEOLOGICAL INTERPRETED SECTION

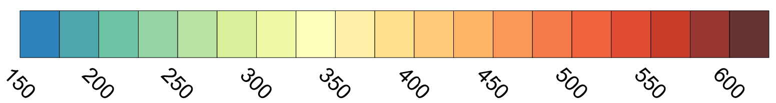






LEGEND

- SAND - LOW COMPACTION
  S-WAVE VELOCITY < 300 m/s
- SAND MODERATE COMPACTION WITH POSSIBLE LITHIFIED SAND/CALCARENITE LENSES
  S-WAVE VELOCITY 300-350 m/s
- 0mAHD
- LIMESTONE - EXTREMELY WEATHERED TO WEATHERED
  LOW ROCK STRENGTH, S-WAVE VELOCITY 350-450 m/s.
- LIMESTONE - WEATHERED TO COMPETENT
  LOW TO MODERATE ROCK STRENGTH. S-WAVE VELOCITY > 450 m/s.



SEISMIC S-WAVE VELOCITY (m/s)

NOTES

Map Projection GDA 94, MGA Zone 50.
Elevation in Australian Height Datum (mAHD)
Refer to Drawing 70488-01 for transect location.
Drawing to be used in conjunction with Report 70488.

CLIENT: SHIRE OF DENMARK	Date	18 February 2019	Paper Size	A3
OCEAN BEACH GEOTECHNICAL AND GEOPHYSICAL SURVEY DENMARK WESTERN AUSTRALIA	Scale	1:400 Ver, 1:1000 Hor	Drawn	TAL
	Drawing	70488-05	Revision	0

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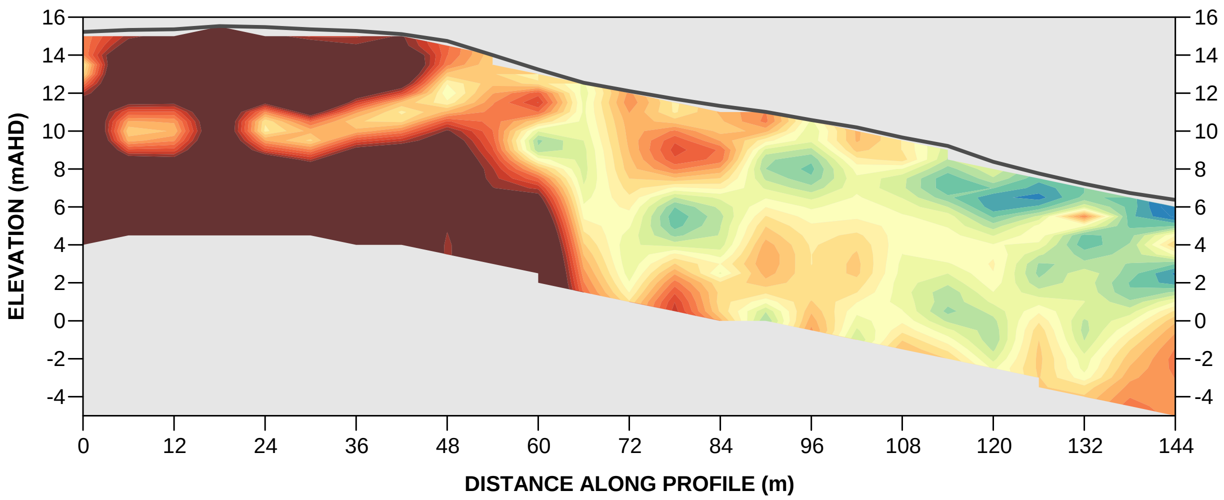
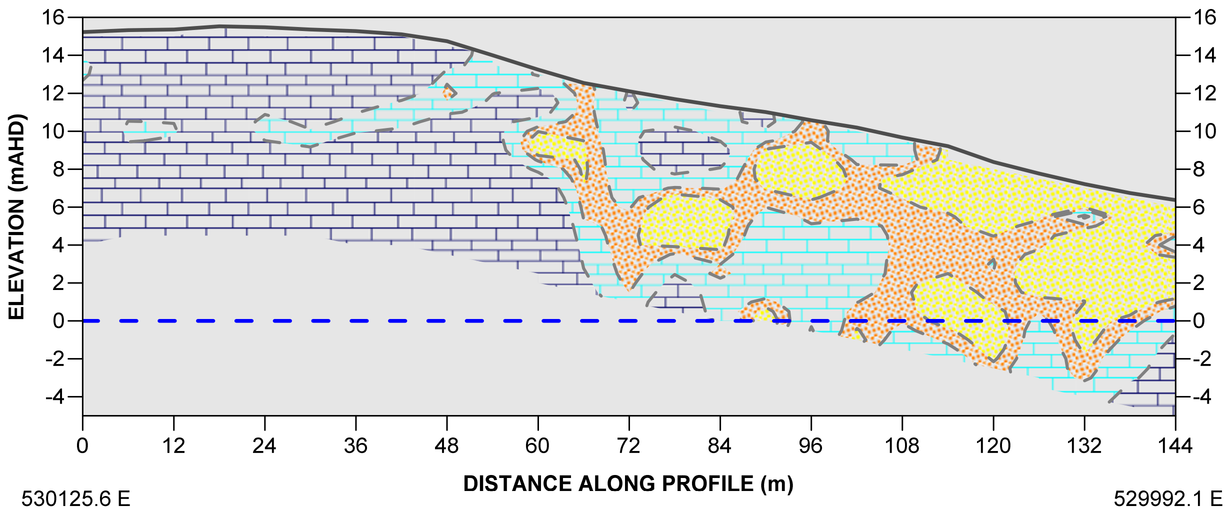
OCEAN BEACH GEOTECHNICAL AND GEOPHYSICAL SURVEY - DENMARK WESTERN AUSTRALIA

TRANSECT - 4

SEISMIC S-WAVE VELOCITY SECTION



GEOLOGICAL INTERPRETED SECTION



530125.6 E
6123558.6 N

529992.1 E
6123596.5 N

LEGEND

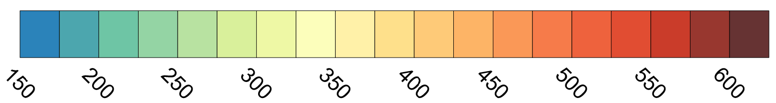
SAND - LOW COMPACTION
S-WAVE VELOCITY < 300 m/s

SAND MODERATE COMPACTION WITH POSSIBLE LITHIFIED SAND/CALCARENITE LENSES
S-WAVE VELOCITY 300-350 m/s

LIMESTONE - EXTREMELY WEATHERED TO WEATHERED
LOW ROCK STRENGTH, S-WAVE VELOCITY 350-450 m/s.

LIMESTONE - WEATHERED TO COMPETENT
LOW TO MODERATE ROCK STRENGTH. S-WAVE VELOCITY > 450 m/s.

0mAHD



SEISMIC S-WAVE VELOCITY (m/s)

NOTES

Map Projection GDA 94, MGA Zone 50.
Elevation in Australian Height Datum (mAHD)
Refer to Drawing 70488-01 for transect location.
Drawing to be used in conjunction with Report 70488.

CLIENT: SHIRE OF DENMARK	Date	18 February 2019	Paper Size	A3
OCEAN BEACH GEOTECHNICAL AND GEOPHYSICAL SURVEY DENMARK WESTERN AUSTRALIA	Scale	1:400 Ver, 1:1000 Hor	Drawn	TAL
	Drawing	70488-06	Revision	0

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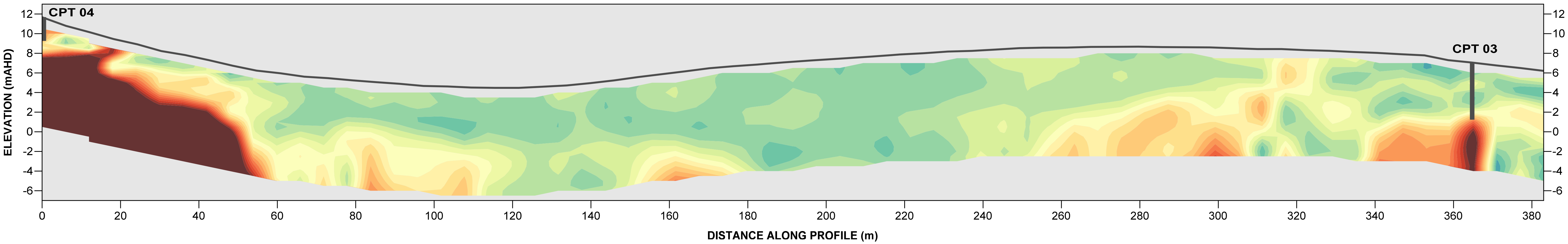
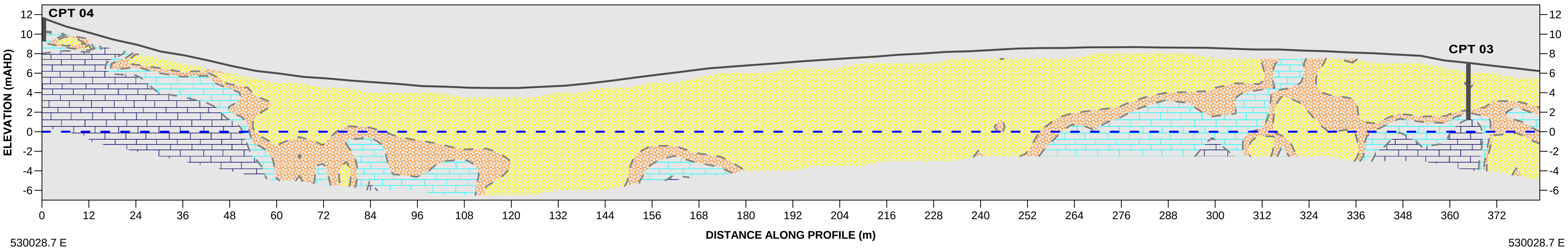
OCEAN BEACH GEOTECHNICAL AND GEOPHYSICAL SURVEY - DENMARK WESTERN AUSTRALIA

TRANSECT - 5

SEISMIC S-WAVE VELOCITY SECTION

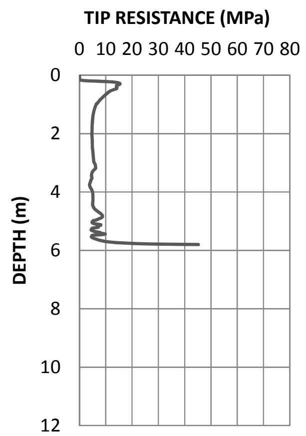


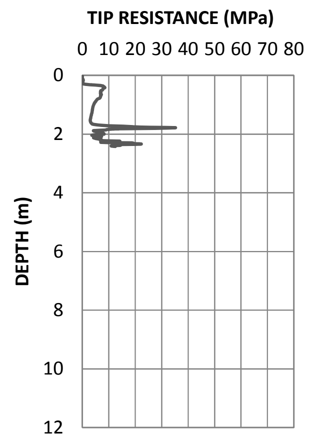
GEOLOGICAL INTERPRETED SECTION



530028.7 E
6123984.0 N

530028.7 E
6123984.0 N





LEGEND

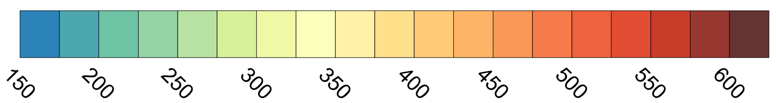
SAND - LOW COMPACTION
S-WAVE VELOCITY < 300 m/s

SAND MODERATE COMPACTION WITH POSSIBLE LITHIFIED SAND/CALCARENITE LENSES
S-WAVE VELOCITY 300-350 m/s

0mAHD

LIMESTONE - EXTREMELY WEATHERED TO WEATHERED
LOW ROCK STRENGTH, S-WAVE VELOCITY 350-450 m/s.

LIMESTONE - WEATHERED TO COMPETENT
LOW TO MODERATE ROCK STRENGTH. S-WAVE VELOCITY > 450 m/s.



SEISMIC S-WAVE VELOCITY (m/s)

NOTES
Map Projection GDA 94, MGA Zone 50.
Elevation in Australian Height Datum (mAHD)
Refer to Drawing 70488-01 for transect location.
Drawing to be used in conjunction with Report 70488.

CLIENT				
SHIRE OF DENMARK	Date	18 February 2019	Paper Size	A3
OCEAN BEACH GEOTECHNICAL AND GEOPHYSICAL SURVEY DENMARK WESTERN AUSTRALIA	Scale	1:400 Ver, 1:1000 Hor	Drawn	TAL
	Drawing	70488-07	Revision	0

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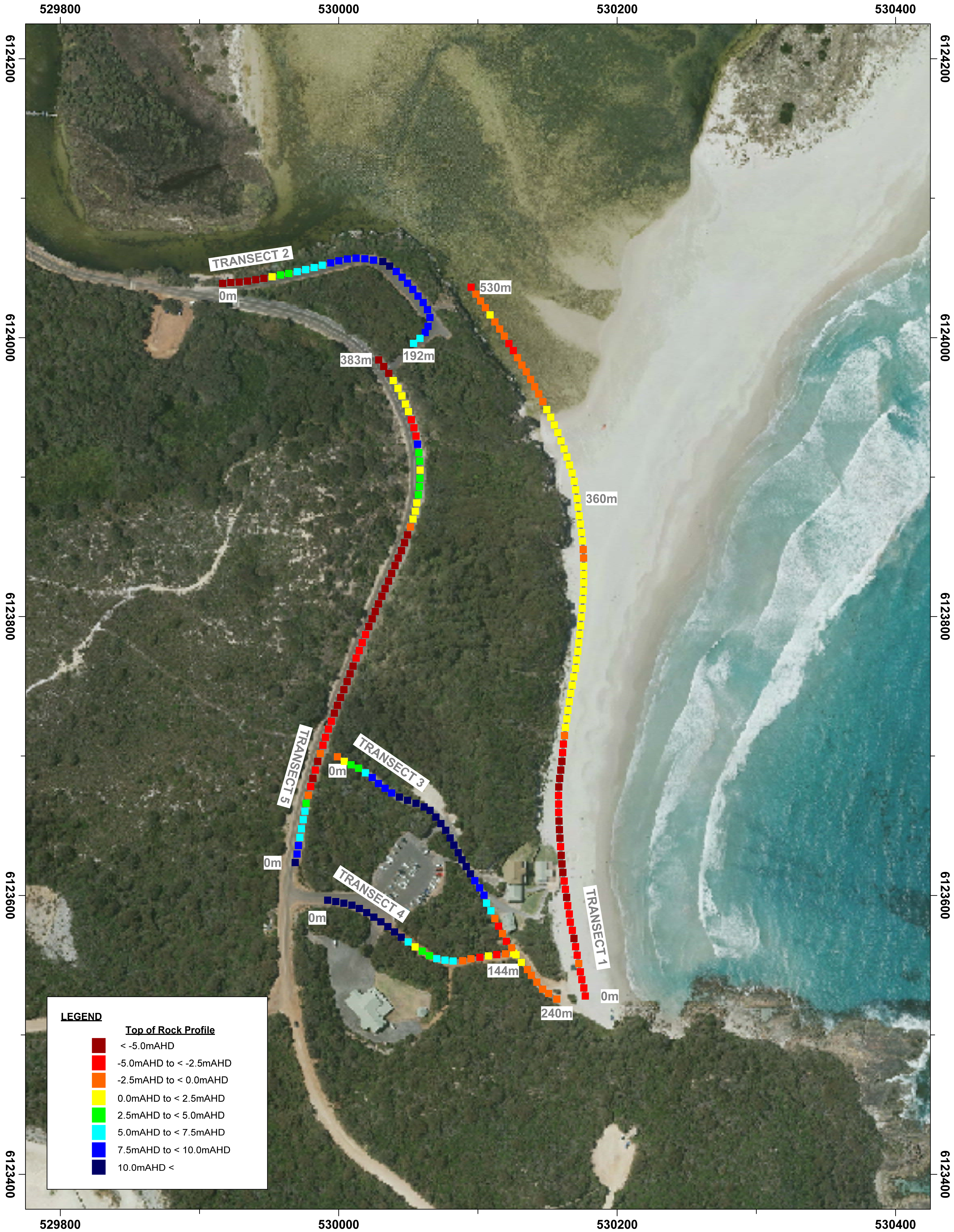
OCEAN BEACH GEOTECHNICAL AND GEOPHYSICAL SURVEY - DENMARK WESTERN AUSTRALIA

MODELLED LEVEL TO TOP OF INTERPRETED ROCK



Date	18 February 2019	Paper Size	A3	CLIENT: SHIRE OF DENMARK
Scale	1:2,500	Drawn	AHWS	OCEAN BEACH GEOTECHNICAL AND GEOPHYSICAL SURVEY DENMARK WESTERN AUSTRALIA
Drawing	70488-08	Revision	0	

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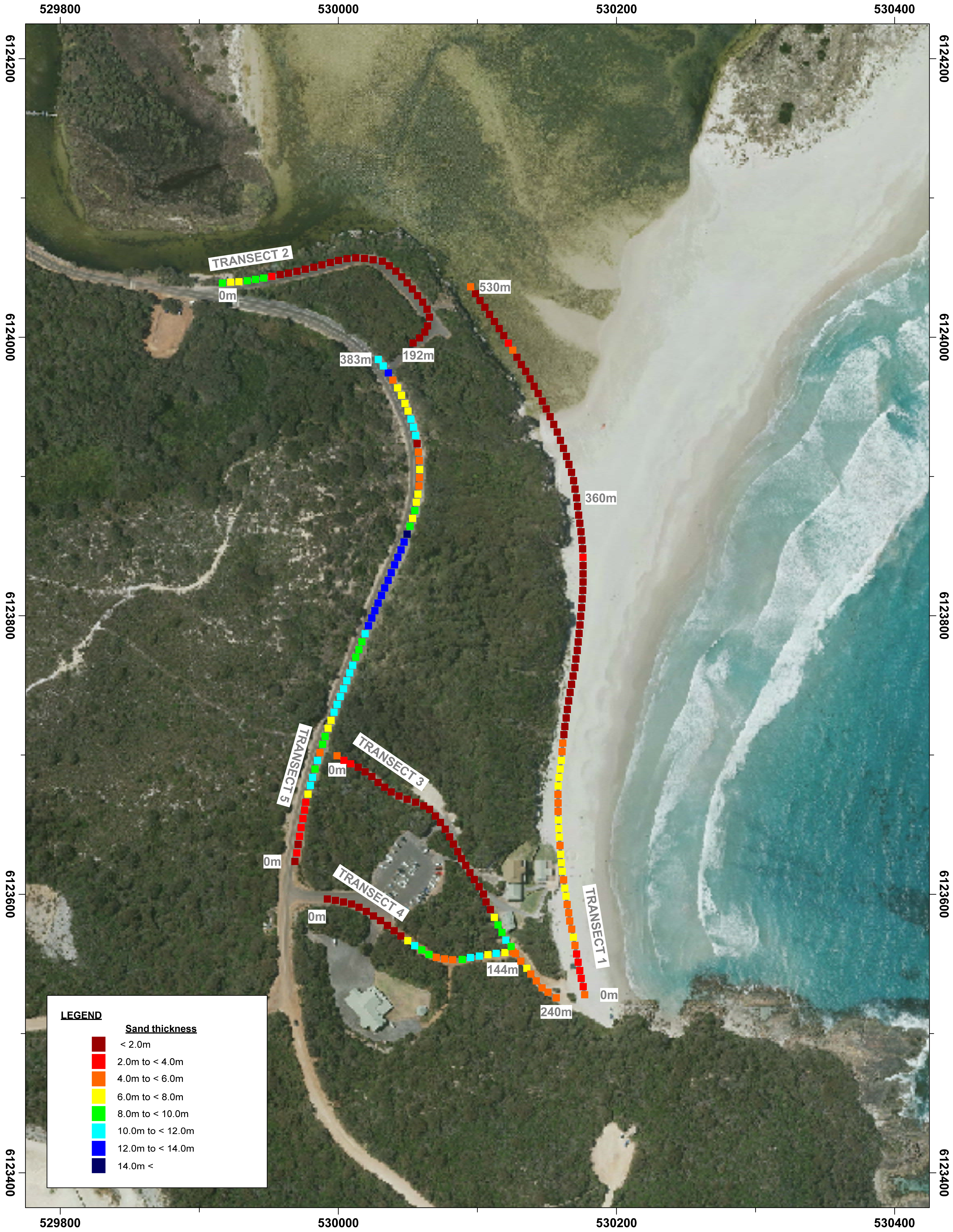
OCEAN BEACH GEOTECHNICAL AND GEOPHYSICAL SURVEY - DENMARK WESTERN AUSTRALIA

MODELLED SAND THICKNESS OVERLYING ROCK



Date	18 February 2019	Paper Size	A3	CLIENT SHIRE OF DENMARK
Scale	1:2,500	Drawn	AHWS	OCEAN BEACH GEOTECHNICAL AND GEOPHYSICAL SURVEY DENMARK WESTERN AUSTRALIA
Drawing	70488-09	Revision	0	

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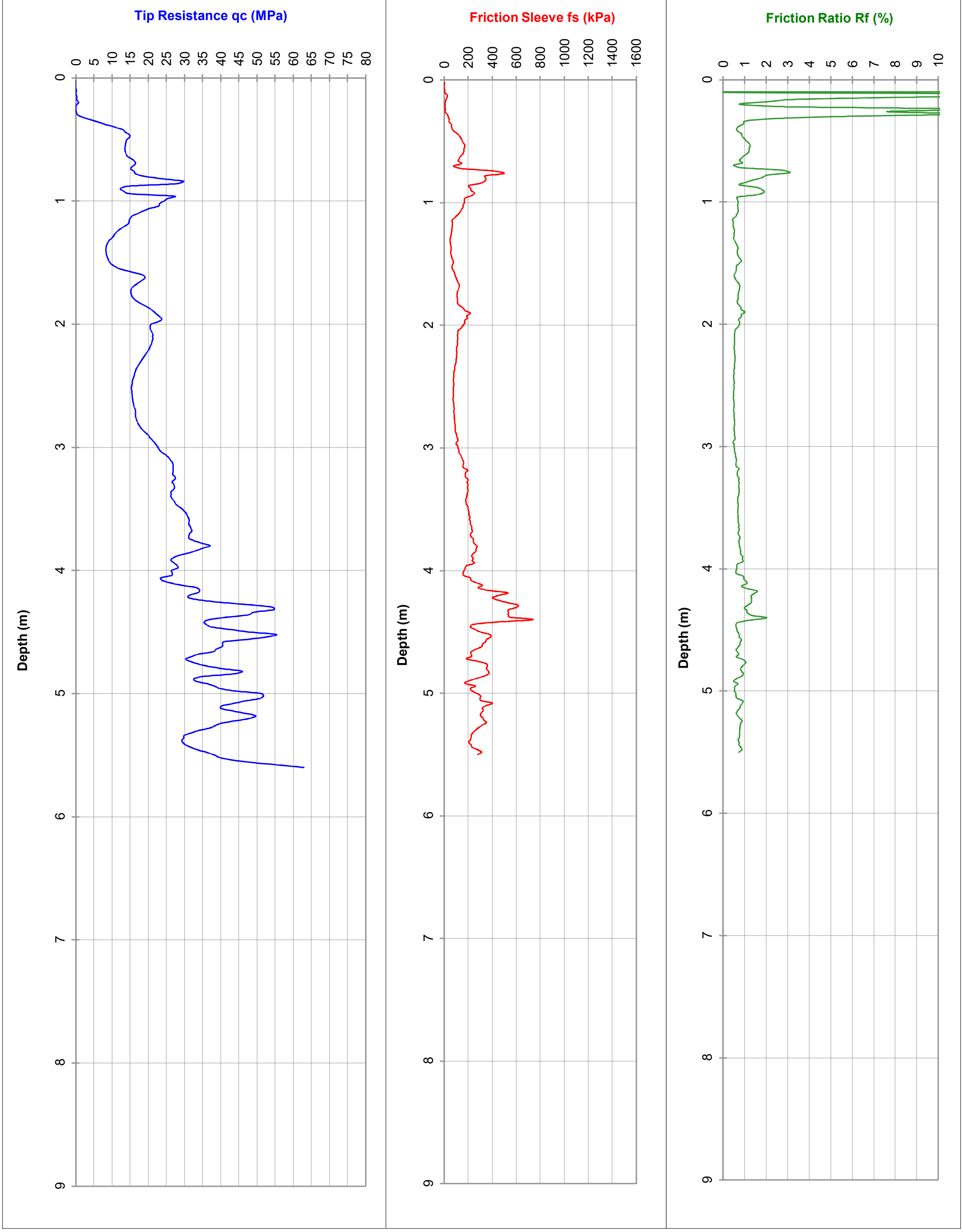
APPENDIX C.
CONE PENETROMETER PLOTS

ELECTRIC FRICTION-CONE PENETROMETER

CLIENT: Shire of Denmark		Job No.: 70488	Probe I.D
PROJECT: Ocean Beach Geotechnical & Geophysical Survey		RL (m):	**CPT 01**
LOCATION: Ocean Beach, W.A		Co-ords:	13-Feb-19



PROBEDRILL GEOTECHNICAL SURVEY

Tested in accordance with AS 1289.6.5.1-1999 and IRTP 2001 for friction reducer

Approx. Water (m): Dry to 0.4

Dummy probe to (m):

Refusal: 63MPa

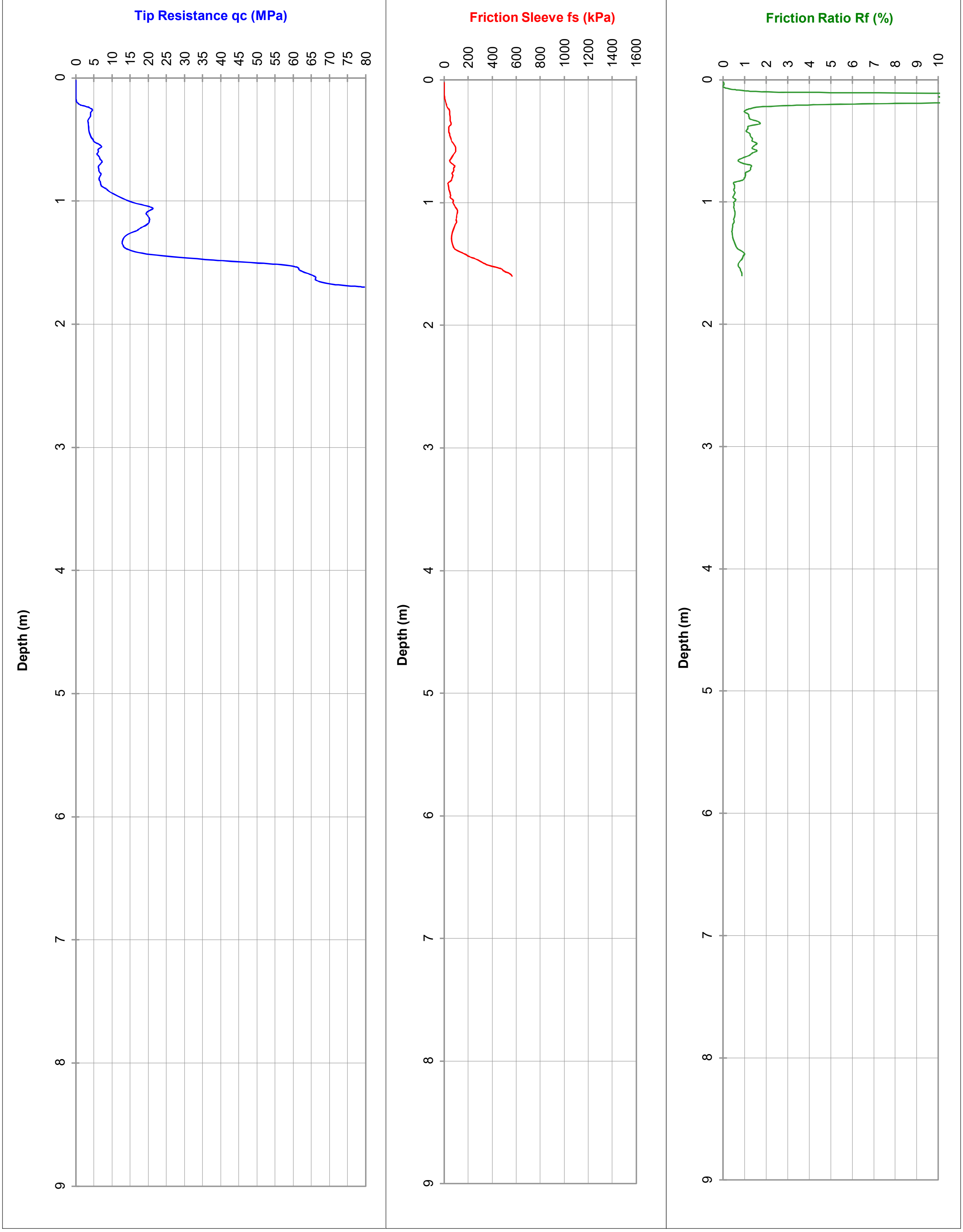
Cone I.D.: EC09

File: GB0095M

Rig Type: 12 tonne track (M1)

ELECTRIC FRICTION-CONE PENETROMETER

CLIENT:	Shire of Denmark	Job No.: 70488	Probe I.D
PROJECT:	Ocean Beach Geotechnical & Geophysical Survey	RL (m):	**CPT 02**
LOCATION:	Ocean Beach, W.A	Co-ords:	13-Feb-19



PROBEDRILL GEOTECHNICAL SURVEY

Tested in accordance with AS 1289.6.5.1-1999 and IRTP 2001 for friction reducer

Approx. Water (m): Dry to 0.1

Dummy probe to (m):

Refusal: 80MPa

Cone I.D.: EC09

File: GB0094M

Rig Type: 12 tonne track (M1)

ELECTRIC FRICTION-CONE PENETROMETER

CLIENT: Shire of Denmark
Job No.: 70488

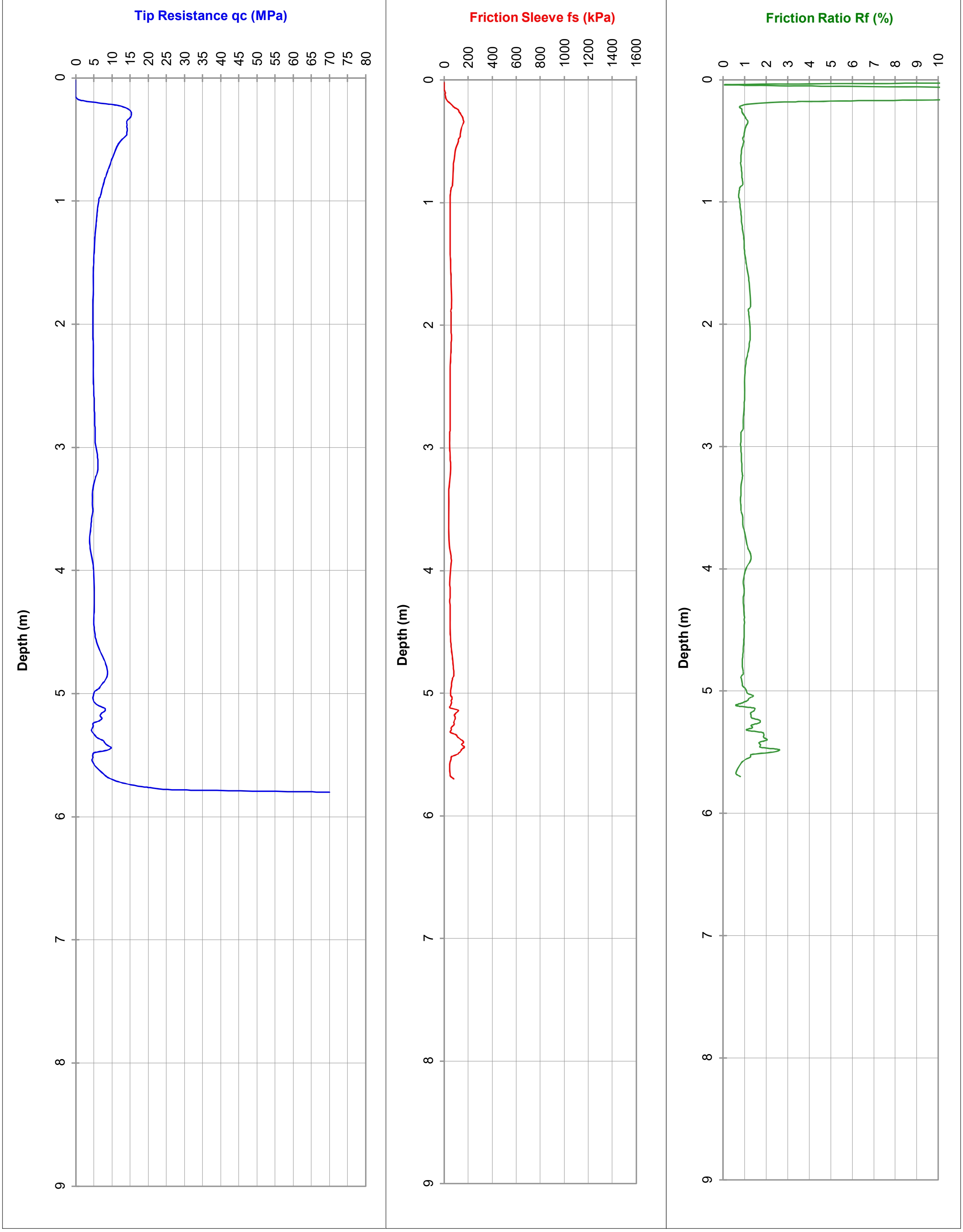
PROJECT: Ocean Beach Geotechnical & Geophysical Survey
RL (m):

LOCATION: Ocean Beach, W.A
Co-ords:

Probe I.D

CPT 03

13-Feb-19



PROBEDRILL GEOTECHNICAL SURVEY

Tested in accordance with AS 1289.6.5.1-1999 and IRTP 2001 for friction reducer

Approx. Water (m): Dry to 5.0

Dummy probe to (m): 0.4

Refusal: 70MPa

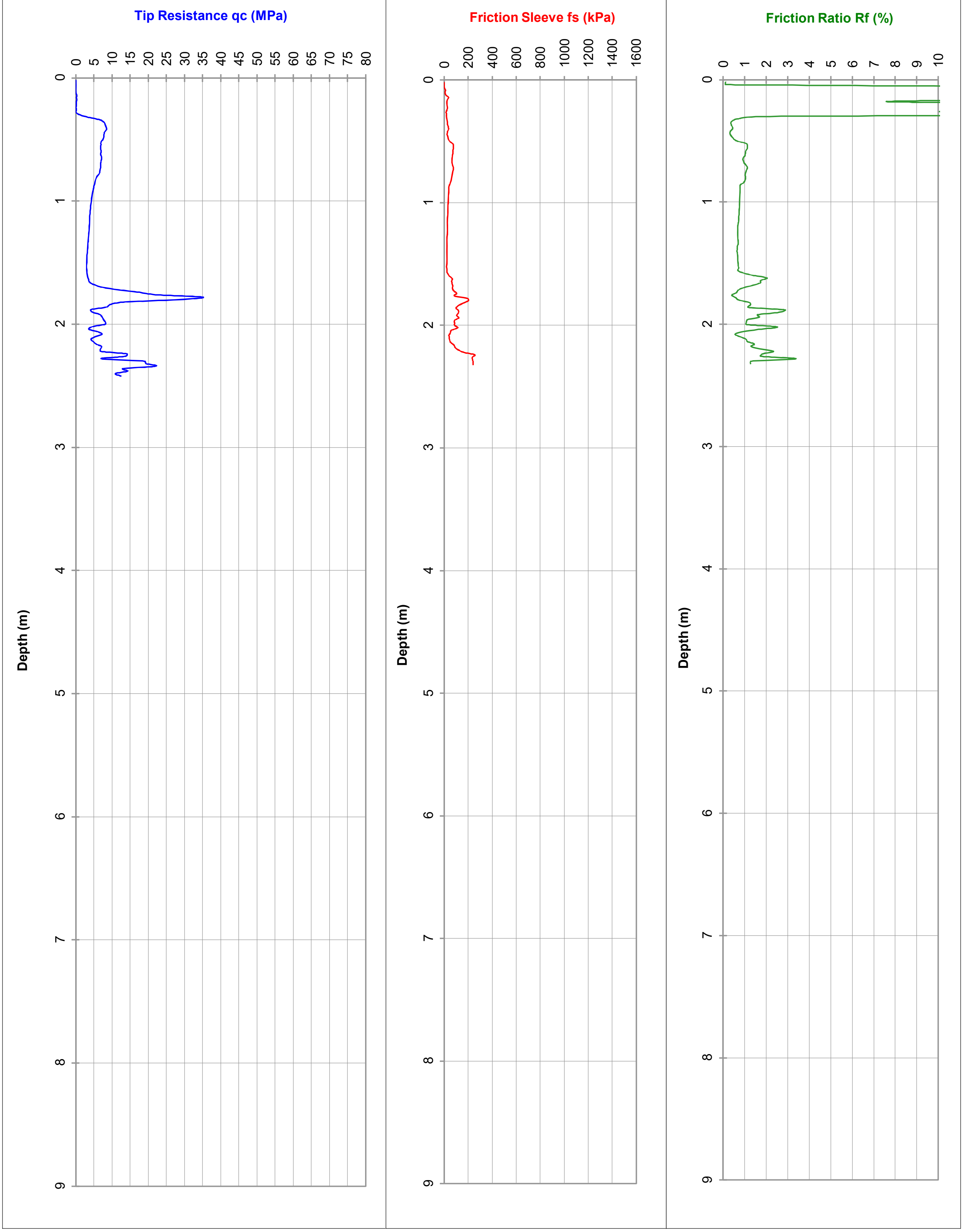
Cone I.D.: EC09

File: GB0096M

Rig Type: 12 tonne track (M1)

ELECTRIC FRICTION-CONE PENETROMETER

CLIENT: Shire of Denmark	Job No.: 70488	Probe I.D
PROJECT: Ocean Beach Geotechnical & Geophysical Survey	RL (m):	CPT 04
LOCATION: Ocean Beach, W.A	Co-ords:	13-Feb-19



PROBEDRILL GEOTECHNICAL SURVEY

Tested in accordance with AS 1289.6.5.1-1999 and IRTP 2001 for friction reducer

Approx. Water (m): Dry to 1.7

Dummy probe to (m): 0.4

Refusal: Inclination

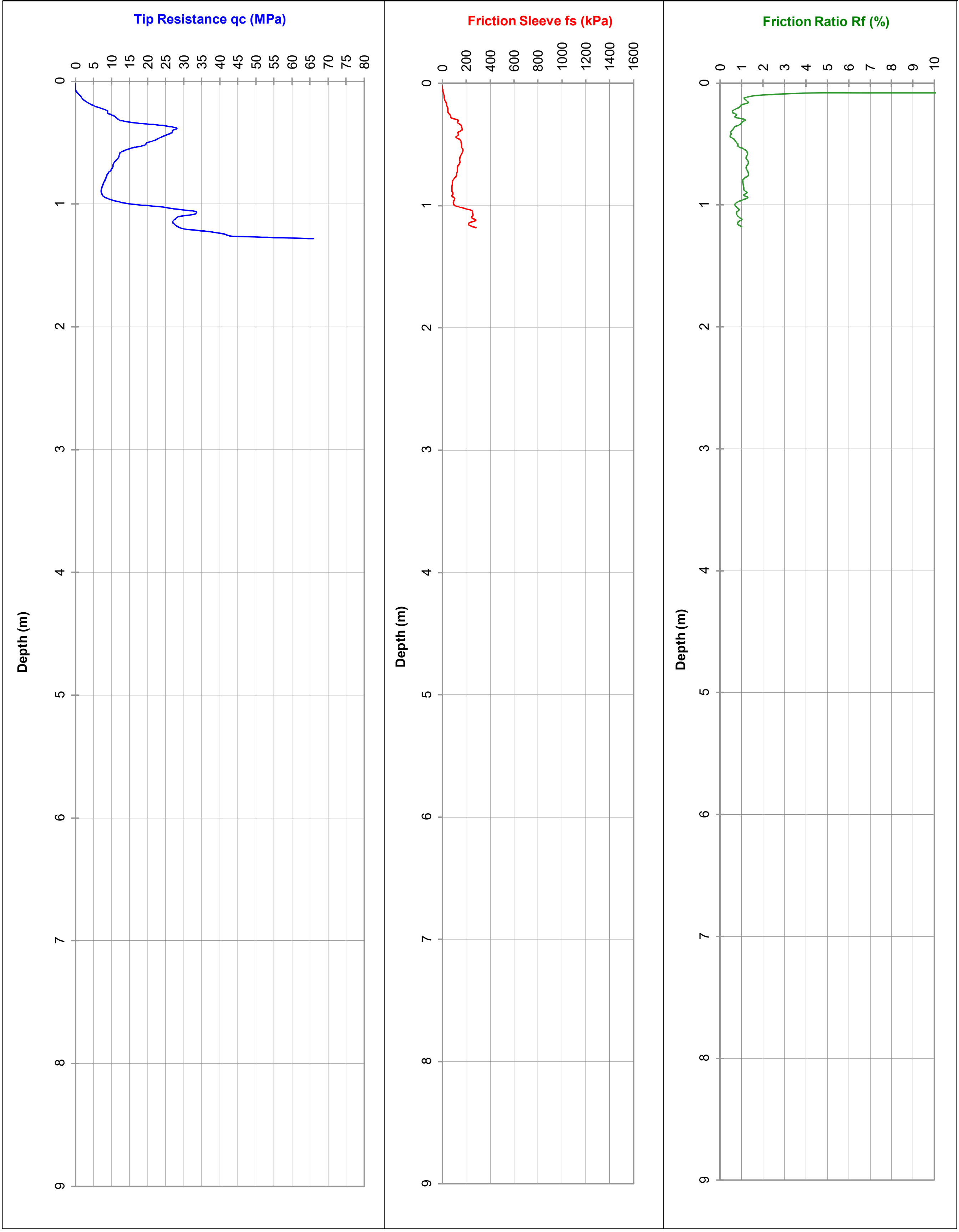
Cone I.D.: EC09

File: GB0097M

Rig Type: 12 tonne track (M1)

ELECTRIC FRICTION-CONE PENETROMETER

CLIENT:	Shire of Denmark	Job No.: 70488	Probe I.D
PROJECT:	Ocean Beach Geotechnical & Geophysical Survey	RL (m):	**CPT 05**
LOCATION:	Ocean Beach, W.A	Co-ords:	13-Feb-19



PROBEDRILL GEOTECHNICAL SURVEY

Tested in accordance with AS 1289.6.5.1-1999 and IRTP 2001 for friction reducer

Approx. Water (m): Dry to 1.2

Dummy probe to (m):

Refusal: 66MPa (Limestone on tip)

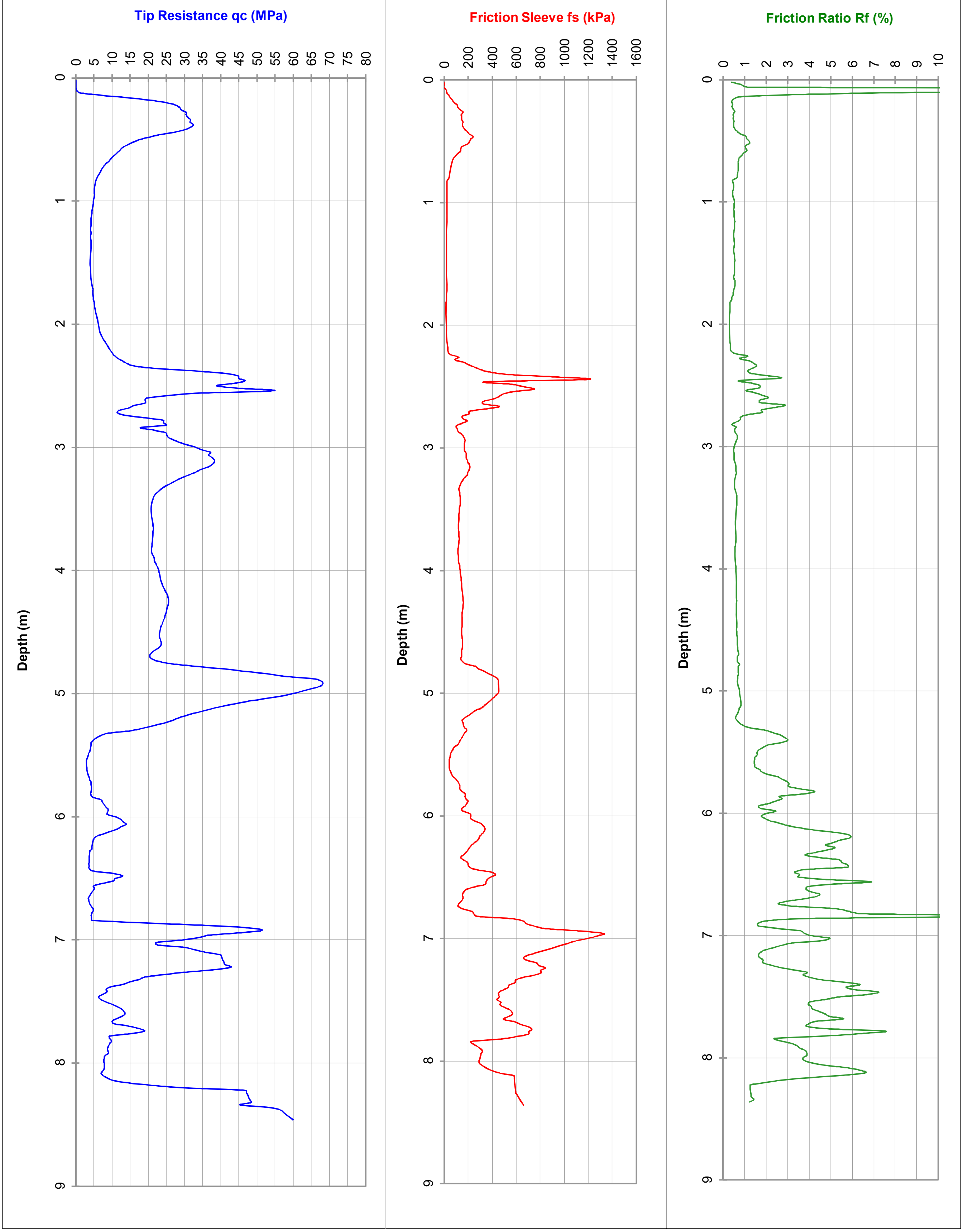
Cone I.D.: EC09

File: GB0098M

Rig Type: 12 tonne track (M1)

ELECTRIC FRICTION-CONE PENETROMETER

CLIENT:	Shire of Denmark	Job No.: 70488	Probe I.D
PROJECT:	Ocean Beach Geotechnical & Geophysical Survey	RL (m):	**CPT 06**
LOCATION:	Ocean Beach, W.A	Co-ords:	13-Feb-19



PROBEDRILL GEOTECHNICAL SURVEY

Tested in accordance with AS 1289.6.5.1-1999 and IRTP 2001 for friction reducer

Approx. Water (m): Dry to 3.2

Dummy probe to (m):

Refusal: 60MPa

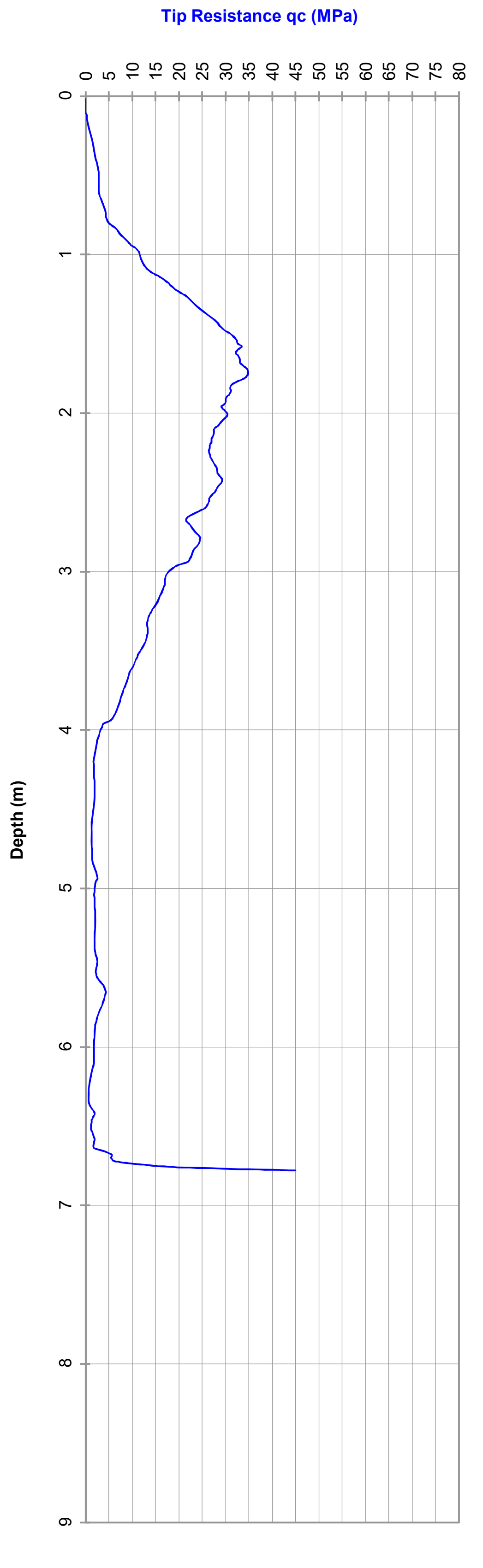
Cone I.D.: EC09

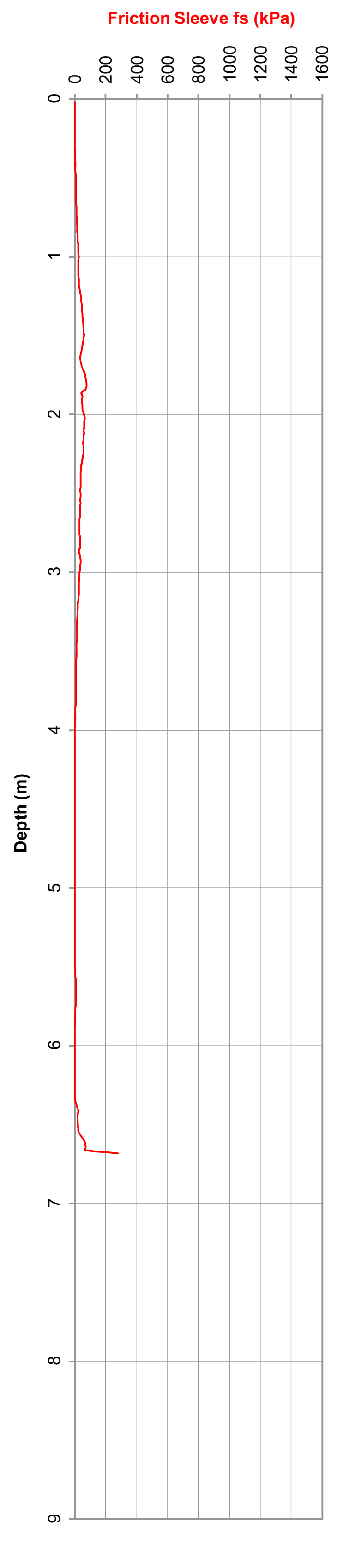
File: GB0103M

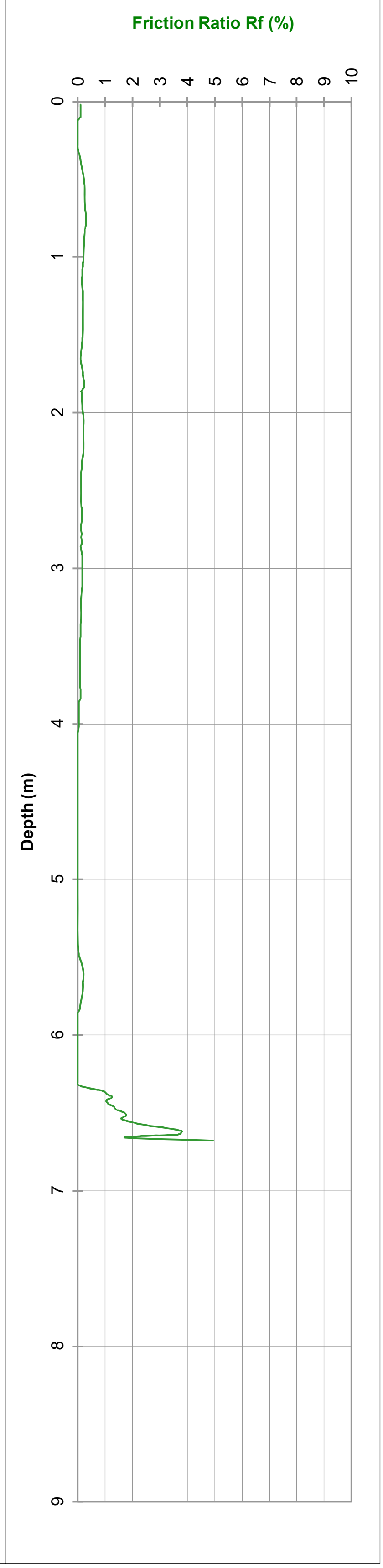
Rig Type: 12 tonne track (M1)

ELECTRIC FRICTION-CONE PENETROMETER

CLIENT: Shire of Denmark	Job No.: 70488	Probe I.D
PROJECT: Ocean Beach Geotechnical & Geophysical Survey	RL (m):	**CPT 07**
LOCATION: Ocean Beach, W.A	Co-ords:	13-Feb-19







PROBEDRILL GEOTECHNICAL SURVEY

Tested in accordance with AS 1289.6.5.1-1999 and IRTP 2001 for friction reducer

Approx. Water (m): 0.9

Dummy probe to (m):

Refusal: 45MPa / No Lateral Rod Support

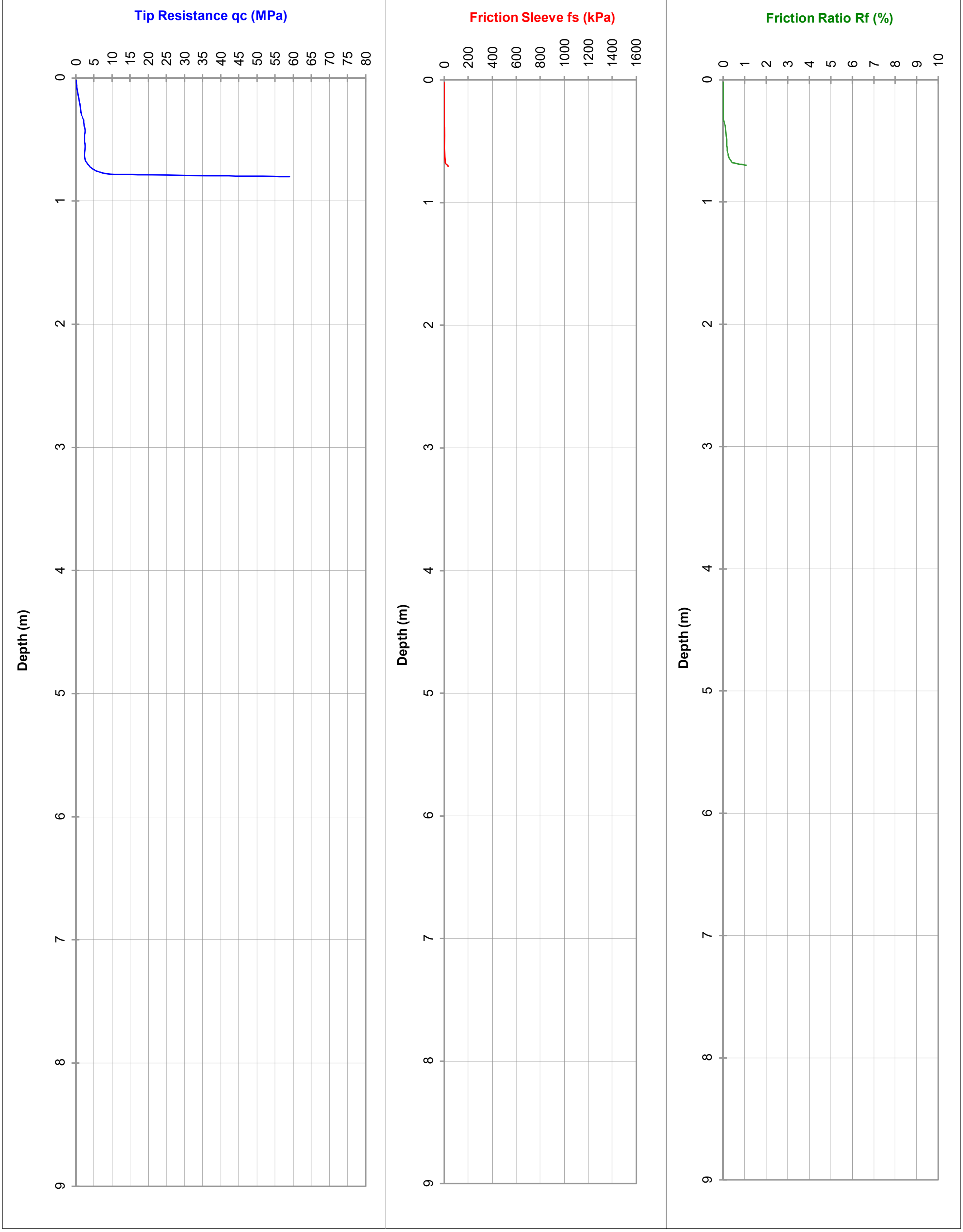
Cone I.D.: EC09

File: GB0102M

Rig Type: 12 tonne track (M1)

ELECTRIC FRICTION-CONE PENETROMETER

CLIENT:	Shire of Denmark	Job No.: 70488	Probe I.D
PROJECT:	Ocean Beach Geotechnical & Geophysical Survey	RL (m):	**CPT 08**
LOCATION:	Ocean Beach, W.A	Co-ords:	13-Feb-19



PROBEDRILL GEOTECHNICAL SURVEY

Tested in accordance with AS 1289.6.5.1-1999 and IRTP 2001 for friction reducer

Approx. Water (m):

Dummy probe to (m):

Refusal: 59MPa

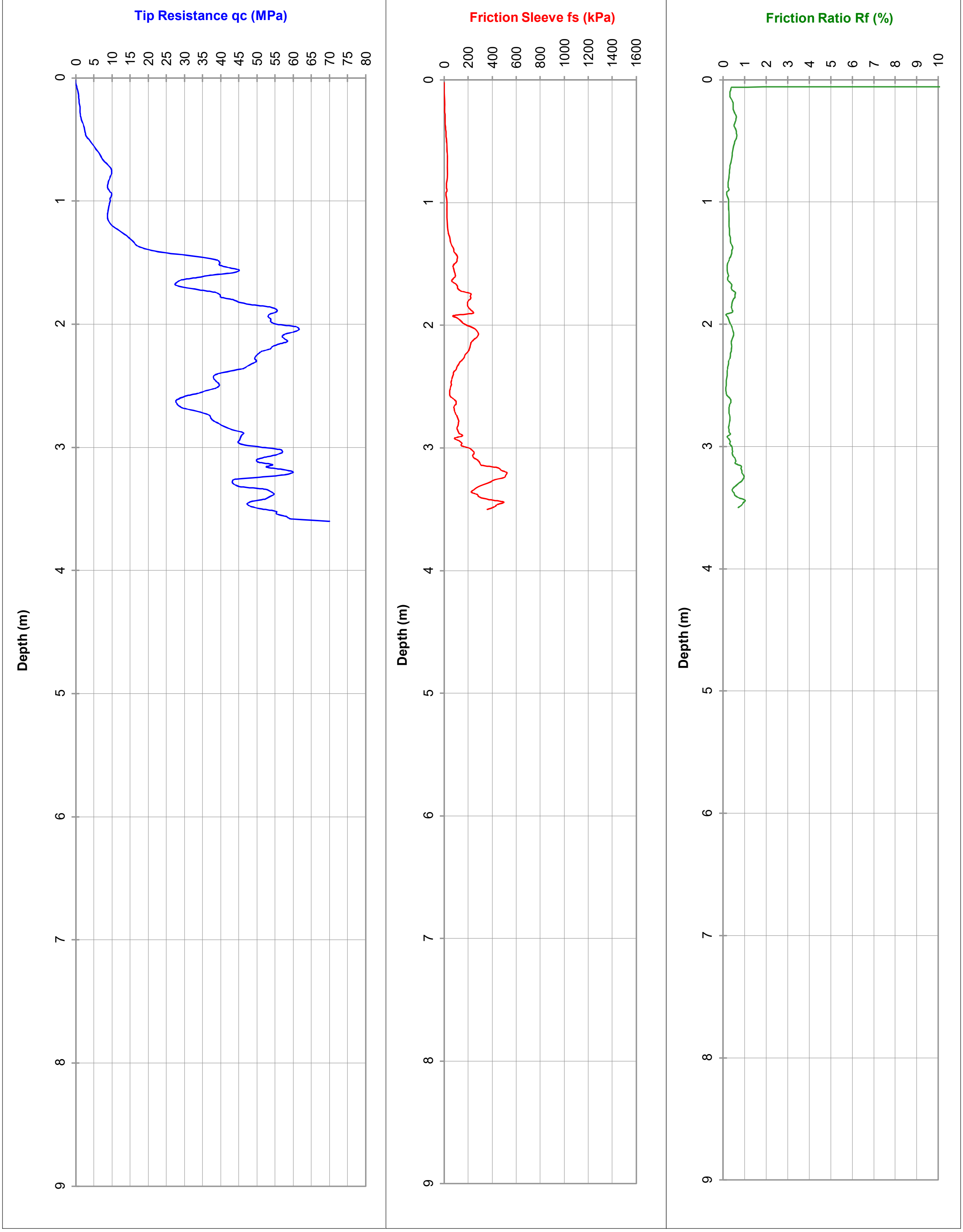
Cone I.D.: EC09

File: GB0101M

Rig Type: 12 tonne track (M1)

ELECTRIC FRICTION-CONE PENETROMETER

CLIENT:	Shire of Denmark	Job No.: 70488	Probe I.D
PROJECT:	Ocean Beach Geotechnical & Geophysical Survey	RL (m):	**CPT 09**
LOCATION:	Ocean Beach, W.A	Co-ords:	13-Feb-19



PROBEDRILL GEOTECHNICAL SURVEY

Tested in accordance with AS 1289.6.5.1-1999 and IRTP 2001 for friction reducer

Approx. Water (m): Dry to 0.2

Dummy probe to (m):

Refusal: 70MPa

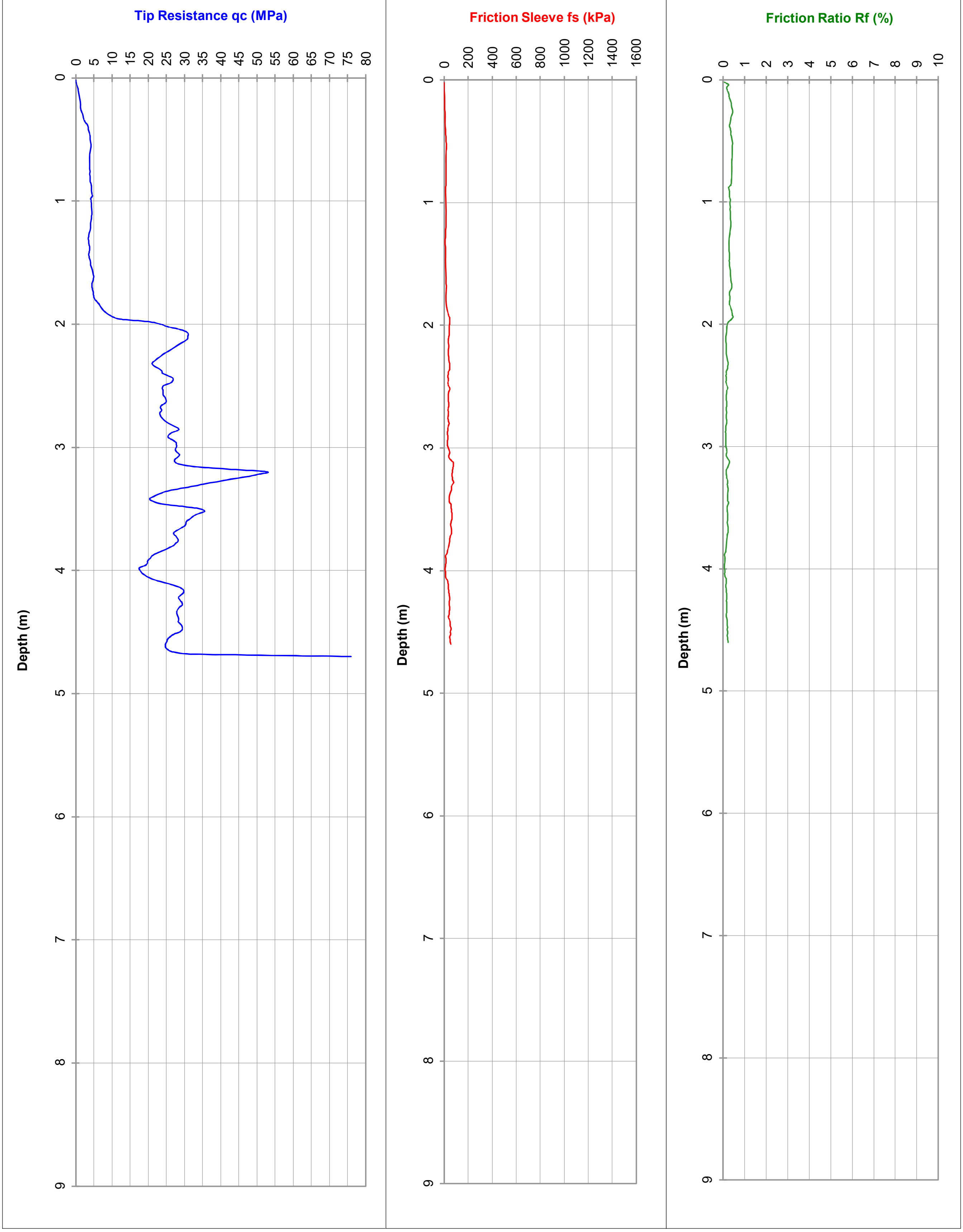
Cone I.D.: EC09

File: GB0100M

Rig Type: 12 tonne track (M1)

ELECTRIC FRICTION-CONE PENETROMETER

CLIENT:	Shire of Denmark	Job No.: 70488	Probe I.D
PROJECT:	Ocean Beach Geotechnical & Geophysical Survey	RL (m):	**CPT 10**
LOCATION:	Ocean Beach, W.A	Co-ords:	13-Feb-19



PROBEDRILL GEOTECHNICAL SURVEY

Tested in accordance with AS 1289.6.5.1-1999 and IRTP 2001 for friction reducer

Approx. Water (m): 0.1

Dummy probe to (m):

Refusal: 76MPa

Cone I.D.: EC09

File: GB0099M

Rig Type: 12 tonne track (M1)

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ALL DATA

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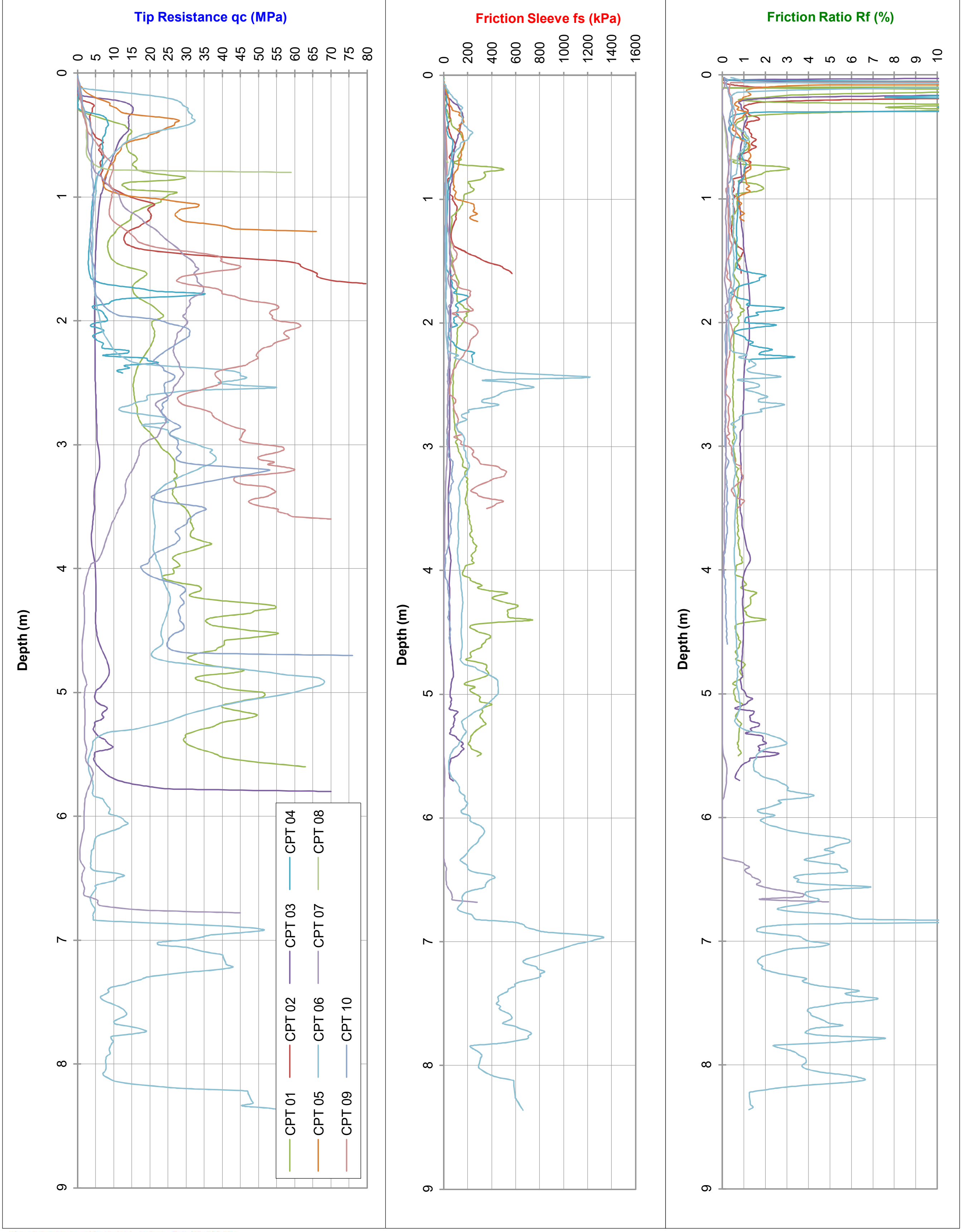
PROJECT: Ocean Beach Geotechnical & Geophysical Survey | Date/s: 13/02/2019

LOCATION: Ocean Beach, W.A



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and IRTP 2001 for friction reducer

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PROBEDRILL GEOTECHNICAL SURVEY

CALIBRATION CERTIFICATE (qc & fs)

CONE ID: EC09

Cone Capacity: qc - 100MPa, fs - 2000kPa
Calibration Date: 7 December 2018
Preliminary Inspection: Pass
Calibrated By: Sean Wilkins
Calibration Procedure: ISO 22476-1:2012, IRTP 2001
Force Application: Compression
Reference Equipment: PT - S type 100kN Serial # 5126009 (Calibrated 22/05/18 - NATA approved Cert. No. 181058)

Note: In accordance with AS1289 F5.1 the force calibration derived by NATA Calibration Certificates are converted to a qc reading in MPa and fs reading in kPa by dividing by 1000 mm² and 15000mm² respectively.

Results of Calibration: Tip (qc)

Applied Force kN	Mean Observed Reading Volts	Mean Calculated Pressure MPa	Accuracy %	Repeatability %	Application Class
0.0	0.00	0.00	0.00	0.00	1
10.0	0.77	10.00	-0.04	0.13	1
20.0	1.54	19.98	-0.11	0.00	1
30.0	2.32	29.97	-0.11	0.04	1
40.0	3.09	39.96	-0.11	0.03	1
50.0	3.86	49.96	-0.09	0.03	1
60.0	4.64	59.99	-0.02	0.02	1
70.0	5.42	70.00	0.00	0.06	1
80.0	6.19	80.00	0.00	0.03	1
90.0	6.97	90.02	0.02	0.00	1
100.0	7.75	100.04	0.04	0.05	1
90.0	6.98	89.91	-0.11	0.07	1
80.0	6.21	79.98	-0.03	0.06	1
70.0	5.44	70.03	0.04	0.06	1
60.0	4.67	60.05	0.09	0.11	1
50.0	3.89	50.05	0.10	0.10	1
40.0	3.11	40.06	0.14	0.13	1
30.0	2.34	30.03	0.09	0.21	1
20.0	1.56	20.00	0.00	0.32	1
10.0	0.78	9.98	-0.23	0.51	1
0.0	0.00	0.00	0.00	0.00	1

R^2 Value = 1.0000

qc Calibration Factor (MPa/Volt): **12.90**

"Class 1" Application Accuracy achieved
Zero Shift Error: 0.00%

Results of Calibration: Friction Sleeve (fs)

Applied Force kN	Mean Observed Reading Volts	Mean Calculated Pressure kPa	Accuracy %	Repeatability %	Application Class
0.0	0.00	0	0.00	0.00	1
3.0	0.74	199	-0.69	0.54	1
6.0	1.49	400	-0.02	0.27	1
9.0	2.23	601	0.16	0.40	1
12.0	2.97	803	0.31	0.37	1
15.0	3.71	1003	0.28	0.16	1
18.0	4.45	1202	0.17	0.09	1
21.0	5.18	1401	0.04	0.15	1
24.0	5.92	1599	-0.05	0.10	1
27.0	6.65	1798	-0.10	0.06	1
30.0	7.39	1998	-0.09	0.07	1
27.0	6.68	1790	-0.55	0.06	1
24.0	5.96	1596	-0.27	0.08	1
21.0	5.24	1400	0.00	0.10	1
18.0	4.51	1204	0.32	0.13	1
15.0	3.78	1007	0.72	0.21	1
12.0	3.05	809	1.11	0.23	1
9.0	2.30	608	1.25	0.39	1
6.0	1.55	404	0.93	0.45	1
3.0	0.78	197	-1.69	0.39	1
0.0	0.00	0	0.00	0.00	1

R^2 Value = 1.0000

fs Calibration Factor (kPa/volt): **270.08**

"Class 1" Application Accuracy achieved
Zero Shift Error: 0.00%

Calibration Checked & Authorised: Michelle Baumer

Job Details

Client: GBG Maps
Date of Job: 13/2/19
Rep: Peter Eccleston
Tip Diameter: 35.40
Location: Denmark
Sleeve Diameter: 35.65