GBGMAPS

Advanced Subsurface Investigations

Report

Two Rocks Geophysical Infill Survey Western Australia.

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CONTENTS

1. EXECUTIVE SUMMARY

This report presents the geophysical investigation undertaken by GBGMAPS for the Government of Western Australia Department of Transport (DoT) along a section of coastal dune and beach foreshore in Two Rocks WA. The objective of the investigation was to provide information on the subsurface material at the site in particular to discern whether there is substantial underlying rock that may protect against dune retreat. The investigation addresses knowledge gaps between previous geophysical investigations by GBGMAPS / Aurecon in May 2014 and March 2016.

As part of the investigation scope, Multi-channel Analysis of Surface Waves (MASW), Seismic Refraction and Cone Penetrometer Test (CPT) datasets were collected along a series of transects within the investigation area. The datasets were processed and analysed to provide colour 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 calibrated with CPT results to generate geological sections showing the modelled depth to competent limestone relative to Mean Sea Level.

The results of the investigation were compiled with the previous investigations to provide an overall assessment of the subsurface conditions of the 1.6km of coastal dune system investigated at Two Rocks. The following observations were made:

- The modelled top of rock is below mean sea level for the majority of the beach transects. This is especially evident at the southern section of the foreshore where the rock level is on average 1.5m to 2.0m deeper than the northern section of foreshore. The rock level rises to above mean sea level at the northern end of the foreshore.

- The modelled top of rock is above mean sea level for the majority of the longitudinal dune transects including along Sovereign Drive. The thickness of sand cover overlying limestone is generally greater at the southern section ranging from 6m to 8m, compared to the northern section where sand cover is present as discrete lenses on average 5m thick and the limestone being at near surface at a number of locations.

- The modelled top of rock is above mean sea level for the majority of the Cross-Shore Transects. The sand cover overlying limestone is generally thicker along the southern Cross-Shore Transects where sand cover ranges from 6m to 11m than the northern Cross-Shore transects where sand cover is generally less than 6m. A potential ridge feature has been identified extending in longitudinal north-south direction at the northern end of Sovereign Drive. The feature appears to be continuous over 5 Cross-Shore transects and up to between 3 to 6.5mAHD.

2. INTRODUCTION

At the request of the Government of Western Australia Department of Transport (DoT), GBGMAPS carried out a geophysical subsurface investigation over a section of coastal dune and beach foreshore in Two Rocks, Western Australia on the 9th of August 2016.

During the investigation Seismic Refraction and Multi-channel Analysis of Surface Waves (MASW) datasets were acquired, processed and analysed along 3 transects. In addition Cone Penetrometer Testing (CPT) was carried out at a number of point locations in order to provide ground truthing and to calibrate the geophysical results. The objective of the investigation was to provide information on the subsurface material at the site in particular to discern whether there is substantial underlying rock that may protect against dune retreat.

This investigation compliments previous geophysical investigations carried out by GBGMAPS for DoT including at Two Rocks to the west of Sovereign Drive (May 2014) and at Northern Two Rocks (March 2016). The current investigation was carried out in order to address knowledge gaps between the existing two investigations.

3. INVESTIGATION SITE

The investigation was carried out over an approximate 250m section of north-south trending coastal dune at the northern end of Sovereign Drive Two Rocks. Figure 2 overleaf shows the extents of the investigation site as an orange dashed polygon.

Surface conditions within the site predominately consisted of sand over the beach foreshore and low vegetation of moderate thickness over the dunes. Photographs of the typical surface conditions at the site are shown in Figure 1 below.

Figure 1: Photographs showing the typical site conditions over the beach foreshore (left image) and over the dunes (right image).

Figure 2: Two Rocks Geophysical Infill Survey extents (orange dashed line). Aerial imagery from Landgate (2016).

4. SUBSURFACE TEST METHODS

During the investigation three 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)** – collected along the beach transect to map the depth to the competent rock.
- **Seismic Refraction** – collected along the dune transects where surface conditions including vegetation and undulating surface topography precluded the use of MASW.
- **Cone Penetrometer Testing (CPT)** – collected at points along the geophysical transects in order to provide ground truthing on the depth to bedrock and to calibrate the geophysical results.

4.1 MULTI-CHANNEL ANALYSIS OF SURFACE WAVES (MASW)

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.

4.2 SEISMIC REFRACTION

Seismic refraction involves the measurement of travel times of seismic compressional waves (P-waves) that are generated at the surface, propagate through the subsurface and return to the surface after being refracted at the interface between layers of contrasting seismic velocity. The method is particularly suitable for mapping bedrock depth and being related to elastic strength and density, the P-wave velocities calculated from the method can be used as a measure of rock hardness.

4.3 CONE PENETROMETER TESTING

CPT is a standard geotechnical test 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 indicated the depth to competent rock.

5. DATA ACQUISITION

The site work was carried out on the 9th August 2016. Geophysical data acquisition was carried out by a three person crew from GBGMAPS consisting of qualified Geophysicists. CPT data acquisition was carried out by Probedrill under the direction of GBGMAPS.

A total of three geophysical transects and CPTs at six locations intersecting the transects were acquired. The extents and locations of the geophysical transects and CPT points are shown in Drawing 70345-01 in Appendix A. Testing carried out for the current investigation are shown as coloured lines and symbols, whilst testing from the previous investigations are shown as grey lines and symbols.

The following testing was carried out during the investigation:

- **Beach Transect 1** - North-south trending transect along the beach foreshore. 270m in length using MASW, with 3 CPTs collected at 12m, 91.5m and 183.5m along the transect.
- **Cross-Shore Transect 1** – East-west trending transect along the dune system. 92m in length using seismic refraction, with 1 CPT collected at 56m along the transect.
- **Cross-Shore Transect 2** - East-west trending transect along the dune system. 92m in length using seismic refraction, with 2 CPTs collected at 50m and 88m along the transect.

5.1 MULTI-CHANNEL ANALYSIS OF SURFACE WAVES

MASW data was acquired using 24, 4.5Hz vibration sensors (geophones) connected via a seismic cable to a Geometrics Seismograph. The geophone array was attached to a land streamer consisting of a Kevlar reinforced tape and metal base plates which the geophones were fixed to at 1 m centres resulting in a total array length of 23m.

Seismic energy was generated using a 5.8kg sledge hammer impacting a 12mm steel plate placed on the ground surface. Zero-time of hammer impact was recorded using a trigger sensor attached to the hammer and connected to the seismograph via a cable. The seismic response was recorded by the seismograph with a time window of 1s at a 0.5ms sample interval.

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 with a source point located 6m before the first geophone, with multiple impacts of the sledge hammer being stacked in order to enhance the seismic signal and suppress noise. The geophone array was then towed by an All-Terrain Vehicle 6m along the profile with the process repeated until the end of the profile was reached.

Figure 3: MASW data acquistion along the Beach Transect, Two Rocks WA.

5.2 SEISMIC REFRACTION

Seismic Refraction data was acquired using 24, 14Hz vibration sensors (geophones) connected via two seismic cables to a Geometrics Seismograph. The geophones were placed into the ground surface using spikes at 4m intervals resulting in a array length of 92m.

Seismic energy was generated using a 5.8kg sledge hammer impacting a 12mm steel plate placed on the ground surface. Zero-time of hammer impact was recorded using a trigger sensor attached to the hammer and connected to the seismograph via a cable. The seismic response was recorded by the seismograph with a time window of 150ms at a 62.5µs sample interval.

Seismic refraction data acquisition involved laying out the geophone array in a straight line along the required transect. Seismic data was recorded at a number of source points both internally within the array and at offset points outside the array. At each source point multiple hammer impacts were stacked in order to enhance the refracted wave signal and suppress noise.

Figure 4: Seismic refraction data acquisition along the Cross-Shore Transect 1, Two Rocks WA.

5.3 CONE PENETROMETER TESTING

CPT data collection was carried under the direction of GBGMAPS using a 12 tonne track mounted Marooka 1 CPT rig operated by a technician from Probe Drill. The CPTs were carried out until refusal was reached with a tip resistance of between 65 and 90MPa. Additional CPTs were made at locations where the refusal depth was less than 3m. Although not reported on these additional tests were made for quality control purposes.

Figure 5: CPT data acquisition at CPT06, Two Rocks WA.

6. GEOPHYSICAL DATA PROCESSING

The collected geophysical datasets were processed and analysed with current industry standard software by qualified geophysicists using GBGMAPS standard processing routines.

6.1 MULTI-CHANNEL ANALYSIS OF SURFACE WAVES

The MASW data was processed using SurfSeis version 4 (Kansas Geological Survey, 2014). Overtone images giving the percentage intensity of phase velocity versus frequency were generated for each collected seismic record. The maximum intensity across the useful range of frequencies was picked for each record resulting in a dispersion curve. The dispersion curves were then run through a 10 layer inversion algorithm to produce an S-wave velocity sounding, showing the varition in modelled S-wave velocity with depth.

The generated S-wave velocity soundings were compiled and gridded using Surfer version 13 (Golden Software, 2016) to produce 2D S-wave velocity sections along the transects. The sections shows variations in the modelled S-wave velocity as per the colour contour scale laterally along the profile and with elevation.

6.2 SEISMIC REFRACTION

The seismic refraction data was processed using Rayfract version 3.33 (Intelligent Resources Incorporated, 2015). The first arrival travel-time picks for each seismic record were imported into Rayfract. A smooth minimum-structure 1D initial model was then generated directly from the seismic refraction first break picks using the horizontally averaging Delta-t-V (improved Wiechert-Herglotz) method. The initial model was then refined with true 2D Wavepath Eikonal Traveltime (WET) tomogram with the inversion algorithm run for a number of iterations until adequate convergence between the initial model and inverted data occurred.

The final P-wave velocity sections generated from the Rayfract inversion were compiled and gridded in Surfer version 13. The sections shows variations in the modelled P-wave velocity as per the colour contour scale laterally along the profile and with elevation.

7. RESULTS AND INTERPRETATION

The results of the Two Rocks Geophysical Infill Survey have been provided Appendices A, B, C and D of this report as follows:

Appendix A – Site Map

- **70345-01**. Site map showing collected geophysical transects and CPT locations overlayed onto Landgate aerial imagery (February 2016) of the site. Coordinates are given in GDA94 MGA Zone 50.

Appendix B – Geophysical and Interpreted Cross Sections

- **70345-02** – Beach Transect 1 S-wave velocity section, interpreted section and CPT plots from chainages 0 to 270m.
- **70345-03** – Cross-Shore Transect 1 P-wave velocity section, interpreted section and CPT plots from chainages 0 to 92m.
- **70345-04** – Cross-Shore Transect 2 P-wave velocity section, interpreted section and CPT plots from chainages 0 to 92m.

  Note: All chainage sections are relative to Drawing 70345-01 in Appendix A.

Appendix C – Cone Penetrometer Test Plots

- **Electric Friction Cone Penetrometer plots** – CPTs 1, 1A, 2, 3, 4, 4A, 5 and 6.
- **Cone Calibration Certificates** – Probedrill, 9 August 2016.

Appendix D – Combined Results of Two Rocks Geophysical Surveys

- **70345-05** – Combined results from Two Rocks Geophysical Surveys, Southern Survey Area (May 2014), Northern Survey Area (March 2016) and Infill Survey Area (August 2016).

7.1 GEOPHYSICAL TRANSECTS

The results of the geophysical transects are presented in three drawings in Appendix A.

At the top of each drawing is the seismic velocity section generated from the MASW data for the S-wave velocity sections and from the seismic refraction data for the P-wave velocity sections. The images show the variations in the seismic wave velocity of the subsurface in metres/second as a colour contour plot as per the colour scale from white, blue, green, yellow, orange, red then brown. The distance along the transects are shown on the horizontal axis and elevation in metres AHD are shown on the vertical axis.

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 plots, from the previous Two Rocks geophysical surveys, and from known or assumed local subsurface conditions. The calculated seismic velocity values have been classed into four categories representing different subsurface conditions:

1. **Very low seismic wave velocity** (Vs <275m/s, Vp <550m/s). Regions with very low seismic wave velocity are interpreted as sand of low compaction.
2. **Low seismic wave velocity** (Vs 275-350m/s, Vp 550-800m/s). Regions with low seismic wave velocity are interpreted as moderately compacted sand.

3. **Moderate seismic wave velocity** (Vs 350-400m/s, Vp 800-1000m/s). Regions with moderate seismic wave velocity are interpreted as limestone of low to moderate rock strength. It is postulated that class represents a weathered limestone and transitional zone to stronger, less weathered limestone below.

4. **Moderate to high seismic wave velocity** (Vs >400m/s, Vp >1000m/s). Regions with moderate to high seismic wave velocity are interpreted as moderate to strong limestone of moderate rock strength. It is postulated that this class represents unweathered or slightly weathered limestone.

Elevations shown in the sections have been obtained from a 2015 topographical survey (DoT Drawing 594-34-01) covering some of the dune system to the north of Sovereign Drive. Note the vertical datum used for the topographical survey was 0.87m below A.H.D. 1971 which was corrected to 0.0m A.H.D before being applied to the geophysical transects and CPT locations. Elevations from the topographic survey have been supplemented with relativel laser levels taking along the transects at the time of the geophysical data acquisition.

Along each transect the depth to interpreted limestone has been divided into three classes relative to Mean Sea Level (MSL) as follows:

1. Sections along the transects where the interpreted limestone is below MSL have been marked in red.

2. Sections along the transects where the interpreted weathered limestone is at MSL have been marked in yellow.

3. Sections along the transects where the interpreted limestone is above MSL have been marked in blue.

A reduced level of 0.0mAHD has been considered to be MSL for the purpose of this investigation. It should however be pointed out that since AHD represents an average MSL inferred from metropolitan and regional areas, this relationship may not be accurate for Two Rocks. Furthermore the relationship 0.0mAHD = MSL represents an average calculated from a Geoscience Australia survey from 1971 (http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/geodetic-datums/australian-height-datum-ahd). As such the relationship between 0.0mAHD and MSL should be used with caution.

7.2 CONE PENETROMETER TESTING

The results of the CPTs are presented in Appendix C showing the plots of cone tip resistance in MPa against depth in metres.

The CPTs returned a tip resistance at refusal ranging from between 65and 95MPa indicating competent rock. The depths below the existing ground level to refusal ranged from 3.12m at

CPT04 to 10.72m at CPT02. Depths to refusal relative to mean sea level ranged from -0.7mAHD at CPT05 to 3.59mAHD at CPT01.

The CPT depth of refusal is a useful indicator of the depth to competent material. However it is not necessarily an accurate measure of the depth to bedrock with the cone potentially encountering a shallow discrete obstruction before refusal into bedrock. In order to mitigate for potential shallow discrete obstructions, where CPT refusal depth was less than 3m an additional CPT was made approximately 5m away.

It was observed during this survey and during the previous Two Rocks geophysical surveys that typically there was a gradual increase in CPT tp resistance prior to refusal. This is suggestive of a upper zone of weathered bedrock where the CPT cone pushes into the low strength limestone before meeting refusal at harder competent bedrock. For calibration of the geophysical dataset the depth to bedrock from the CPT was picked to be at the start of the increase in tip resistance not at refusal.

7.3 COMPARISON WITH PREVIOUS TWO ROCKS GEOPHYSICAL SURVEYS

GBGMAPS previously carried out geophysical investigations at Two Rocks to the north and south of the current site, including:

- Two Rocks Geophysical Survey (May 2014) – the results of which are provided in the Aurecon report 241618, 12 June 2014.
- Northern Two Rocks Geophysical Survey (March 2016) – the results of which are provided in the Aurecon report 241618-GET-01, 12 April 2016.

The previous geophysical investigations utilised the same test methods as the current investigation including MASW, seismic refraction and CPT and as such comparison of the results is possible. Drawing 70345-05 in Appendix D provides a summary of the results from the previous and current investigations in a large (A0 page) format.

An overall comparison of the results from the three geophysical investigations at Two Rocks suggests differences in the continuity of the underlying rock over the 1.6km of coastal dune system surveyed. In particular the following trends are observed:

Beach Transects – For the majority of the beach transects the modelled top of rock is below mean sea level. This is especially evident at the southern section of the foreshore (from the northern marina spur groyne to near the beach access steps towards the northern end of Sovereign Drive) where the rock level is on average 1.5m to 2.0m deeper than the northern section of foreshore. The rock level does rise above mean sea level at the northern end of the site. Note the beach transects collected during the May 2014 Survey consisted of five, 50m long transects and did not sample the entire length of beach foreshore.

Sovereign Drive Transect and Dune Transects – The modelled top of rock is above mean sea level for the majority of the Sovereign Drive, Dune Tie-In and Dune Transects. The level to top of rock is on average 4m deeper along the Sovereign Drive and Due Tie-In Transects (May 2014 Survey) than the Dune Transect (March 2016 Survey). The thickness of sand cover overlying limestone is greater at the southern section ranging from 6m to 8m, compared to the northern section where sand cover is present as discrete lenses on average 5m thick and the limestone being at near surface at a number of locations.

Cross-Shore Transects – The modelled top of rock is above mean sea level for the majority of the eleven Cross-shore Transects collected during the southern, northern and infill surveys. The top of rock is observed to be below mean sea level at the western end of Cross-Shore 1 (May 2014 Survey) where the coastal dune opens to a basin adjacent to the beach foreshore. As with the Sovereign Drive and Dune Transects, the sand cover overlying limestone is generally thicker along the southern Cross-Shore Transects where sand cover ranges from 6m to 11m than the northern Cross-Shore transects where sand cover is generally less than 6m.

Analysis of the Cross-Shore transects at the northern end of Sovereign Drive including C-S Transects 1, 2 and 3 (May 2014 Survey) and C-S Transects 1 and 2 (August 2016 Survey) indicates the potential of a ridge of competent rock extending in longitudinal north-south direction. The feature appears to be continuous (intersecting up to 5 of the cross-shore transects) and up to between 3 to 6.5mAHD. The inferred location of the ridge feature is shown as a black dashed line in Figure 6 below. Note the dashed line represents the interpolated alignment of the ridge feature through the intersection points shown as blue crosses along the cross-shore transects. The continuity of the ridge along the entire alignment cannot be determined from the geophysical dataset however it appears to be a prominent geological feature.

Figure 6: Inferred extent of identified ridge feature.

It should be noted that different topographical surveys have been applied to the geophysical datasets and as such discrepancies between the elevations is expected. The following topographical surveys were used:

- Two Rocks Geophysical Survey (May 2014) – a 2002 topographical survey was used for the Sovereign Drive, Dune Tie-In and Cross-Shore Transects, whilst a 2012 topographical survey was used for the Beach Transects. The elevations for all transects were later re-corrected using a July 2014 topographical survey and re-issued to DoT in September 2014.

- Northern Two Rocks Geophysical Survey (March 2016) – Surveyors from McMullen Nolan Group (MNG) were commissioned to obtain levels using RTK GPS receiver along the collected geophysical transects and CPT points at the time of the geophysical survey.

- Two Rocks Geophysical Infill Survey (August 2016) – a 2015 topographical survey (DoT, 594-34-01) was used to obtain levels along the geophysical transects and CPT points.

8. CONCLUSIONS AND RECOMMENDATIONS

A geophysical investigation has been carried out along a 250m section of coastal dune system as part of the Two Rocks Geophysical Infill Survey. During the investigation Seismic Multi-channel Analysis of Surface Waves, Seismic Refraction and Cone Penetrometer Testing datasets were collected along a series of transects over the investigation area in order to address knowledge gaps between the existing May 2014 and March 2016 Geophysical Surveys.

The results of the investigation have been provided in a number of drawings showing the variation in seismic S-wave or P-wave velocity both laterally and with depth relative to 0.0mAHD. The seismic velocities have been interrogated for the depth to competent rock level relative to the current mean sea level with reference to the CPT resistance plots.

The results of the investigation have been compiled with the previous investigations from May 2014 and March 2016 in order to give an overall subsurface assessment of the Two Rocks coastal dune system. The combined results from the three investigations spatially show fair coverage of the coastal dune system with longitudinal transects collected continuously and approximately 100m east of the beach foreshore, and 11 cross-shore transects at an average 160m separation.

An information gap is present along the southern section of the beach transects which were collected as five, 50m long transects during the May 2014 investigation. It is recommended that the southern portion of the beach transects be recollected as a continuous transect from the northern marina spur groyne to Beach Transect 1 of the August 2016 geophysical infill survey. Furthermore CPT can be potentially collected along this section as access for the CPT rig south of the beach access stairs is now possible due to dune retreat. Additional geophysical testing and CPT along this section will address this information gap and improve the overall understanding of the underlying geological features at Two Rocks.

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. 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 on (08) 6436 1599.

For and on behalf of
GBGMAPS PTY LTD

ANDREW SPYROU

Senior Geophysicist

APPENDIX A.
SITE MAP

GBGMAPS
Advanced Subsurface Investigations

TWO ROCKS COASTAL VULNERABILITY STUDY, WESTERN AUSTRALIA

GEOPHYSICAL PROFILES AND CONE PENETROMETER TEST POINTS

Drawing No. 70345-01

LEGEND

- Geophysical Beach Transect (GBGMAPS August 2016)
- Geophysical Cross-shore Transect (GBGMAPS August 2016)
- Cone Penetrometer Test Point (Probe Drill August 2016)
- Geophysical Transect Previous Study *
- Cone Penetrometer Test Point Previous Study *

* Previous studies include -
Two Rocks, May 2014
Northern Two Rocks, March 2016

N

Metres
0 25 50 75 100

NOTES
Coordinates are in GDA94, MGA Zone 50.
Aerial image from Landgate February 2016
Drawing to be used in conjunction with report 70345, refer to report for investigation details, exclusions and limitations.

Date	10 August 2016	Paper Size	A3
Scale	1:2000	Drawn	AHWS
Drawing	70345-01	Revision	A-1

CLIENT **DEPARTMENT OF TRANSPORT**

GEOPHYSICAL INFILL INVESTIGATION FOR COASTAL VULNERABILITY STUDY, TWO ROCKS WESTERN AUSTRALIA

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APPENDIX B.
GEOPHYSICAL SECTIONS

GBGMAPS
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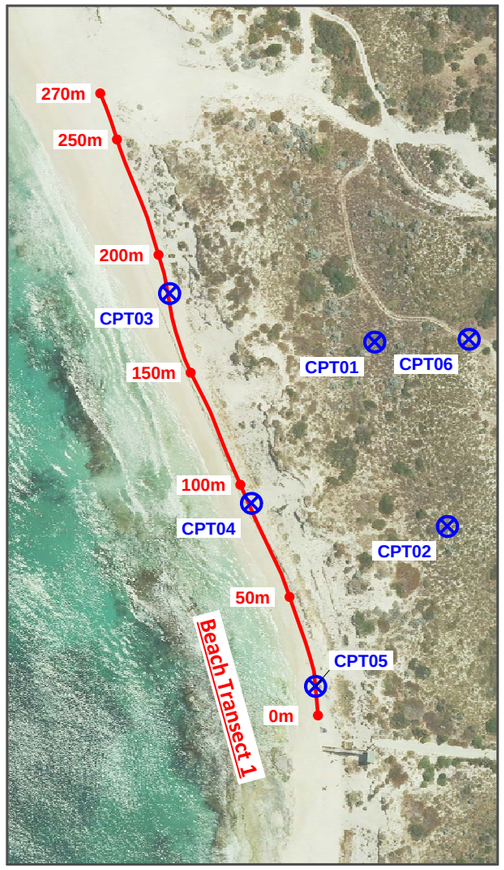
TWO ROCKS COASTAL VULNERABILITY STUDY, WESTERN AUSTRALIA

GEOPHYSICAL PROFILES AND CONE PENETROMETER TEST POINTS

Drawing No. 70345-02

Elevation presented in mAHD
is correct to +/- 0.25m



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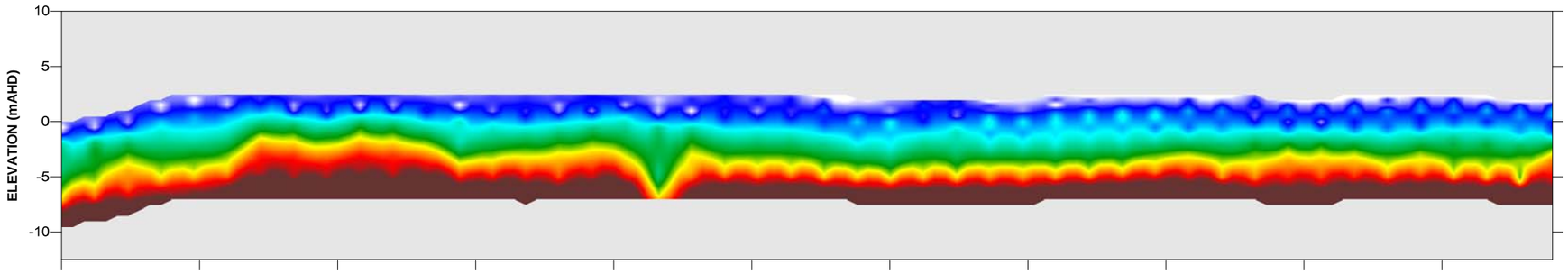

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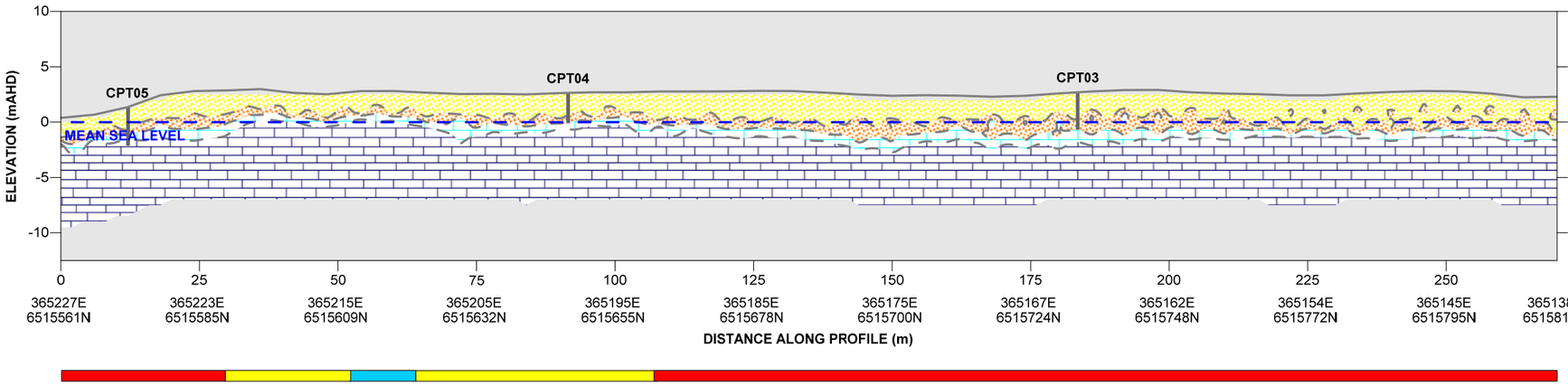
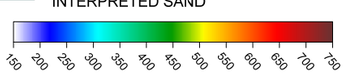


LEGEND

- SAND - LOW COMPACTION
  S-WAVE VELOCITY < 275 m/s
- SAND - MODERATE COMPACTION
  S-WAVE VELOCITY 275-350 m/s
- LIMESTONE - INTERPRETTED LOW TO MODERATE
  ROCK STRENGTH, S-WAVE VELOCITY 350-400 m/s.
- LIMESTONE - INTERPRETED MODERATE ROCK
  STRENGTH, S-WAVE VELOCITY > 400 m/s.
- MEAN SEA LEVEL WITHIN INTERPRETED
  MODERATE STRENGTH LIMESTONE
- MEAN SEA LEVEL WITHIN INTERPRETED
  SOFT/MODERATE STRENGTH LIMESTONE
- MEAN SEA LEVEL WITHIN
  INTERPRETED SAND



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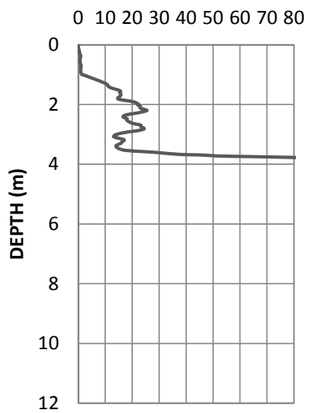

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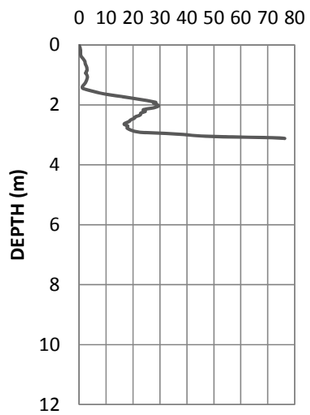

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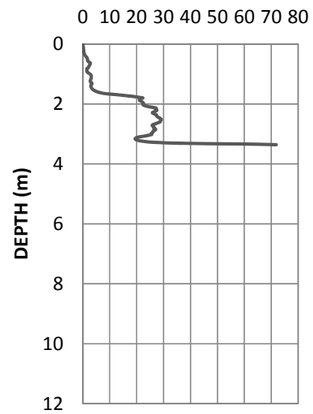

Vertical
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0 10 20 30 40 50
Horizontal

NOTES

Coordinates are in GDA94, MGA Zone 50.
Aerial image from Landgate February 2016
Drawing to be used in conjunction with report 70345, refer to report for investigation details, exclusions and limitations.

Date	10 August 2016	Paper Size	A3
Scale	1:1000 horizontal 1:500 vertical	Drawn	AHWS
Drawing	70345-02	Revision	A-1

CLIENT **DEPARTMENT OF TRANSPORT**

GEOPHYSICAL INFILL INVESTIGATION FOR COASTAL VULNERABILITY STUDY, TWO ROCKS WESTERN AUSTRALIA

GBGMAPS
Advanced Subsurface Investigations

Level 1, 2 Sabre Crescent, Jandakot WA 6164
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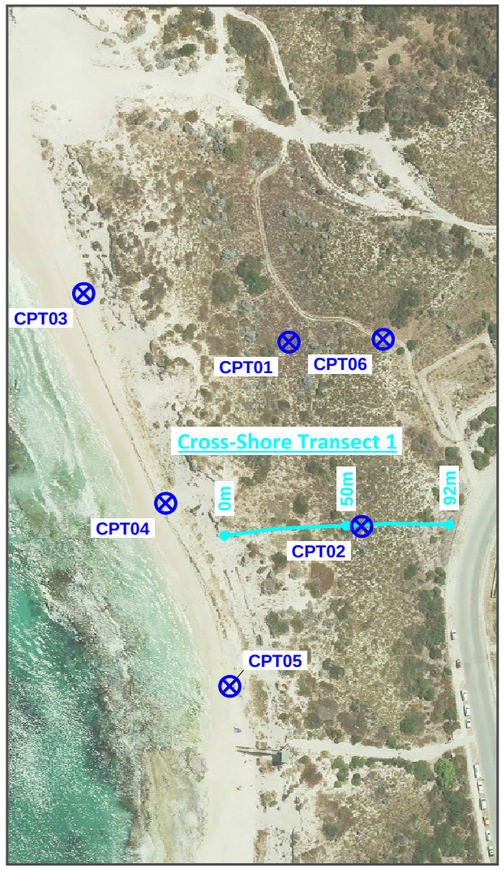
TWO ROCKS COASTAL VULNERABILITY STUDY, WESTERN AUSTRALIA

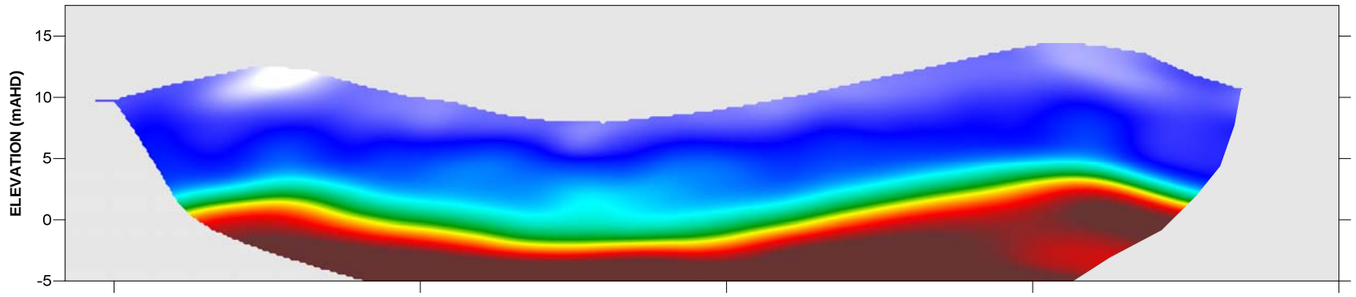
GEOPHYSICAL PROFILES AND CONE PENETROMETER TEST POINTS

Drawing No. 70345-03

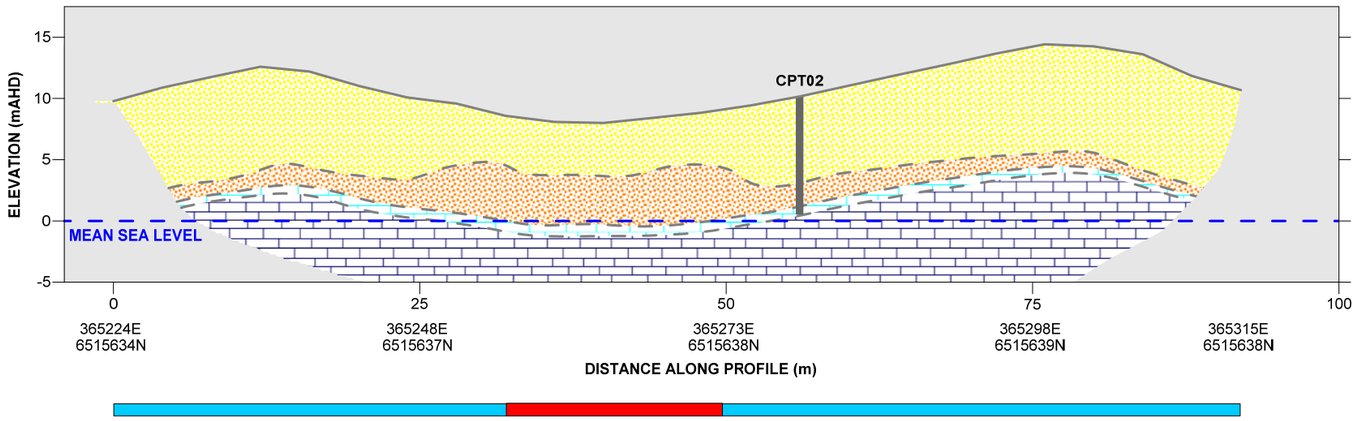
Elevation presented in mAHD is correct to +/- 0.25m



CROSS-SHORE TRANSECT 1 - SEISMIC P-WAVE VELOCITY SECTION

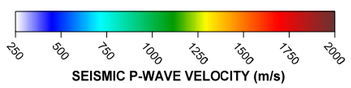


CROSS-SHORE TRANSECT 1 - INTERPRETED SECTION

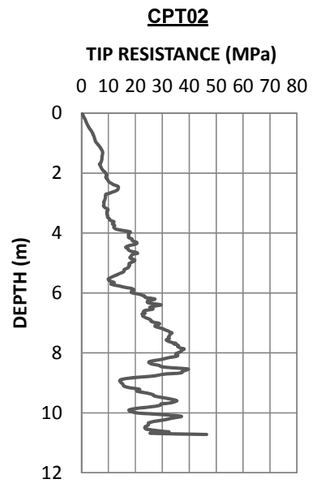


LEGEND

- SAND - LOW COMPACTION P-WAVE VELOCITY < 550 m/s
- SAND - MODERATE COMPACTION P-WAVE VELOCITY 550-800 m/s
- LIMESTONE - INTERPRETTED LOW TO MODERATE ROCK STRENGTH, P-WAVE VELOCITY 800-1000 m/s.
- LIMESTONE - INTERPRETED MODERATE ROCK STRENGTH, P-WAVE VELOCITY > 1000 m/s.
- MEAN SEA LEVEL WITHIN INTERPRETED MODERATE STRENGTH LIMESTONE
- MEAN SEA LEVEL WITHIN INTERPRETED SOFT/MODERATE STRENGTH LIMESTONE
- MEAN SEA LEVEL WITHIN INTERPRETED SAND



CPT02



Metres
0 5 10 15 20 25

NOTES
Coordinates are in GDA94, MGA Zone 50.
Aerial image from Landgate February 2016
Drawing to be used in conjunction with report 70345, refer to report for investigation details, exclusions and limitations.

Date	10 August 2016	Paper Size	A3
Scale	1:500	Drawn	AHWS
Drawing	70345-03	Revision	A-1

CLIENT **DEPARTMENT OF TRANSPORT**

GEOPHYSICAL INFILL INVESTIGATION FOR COASTAL VULNERABILITY STUDY, TWO ROCKS WESTERN AUSTRALIA

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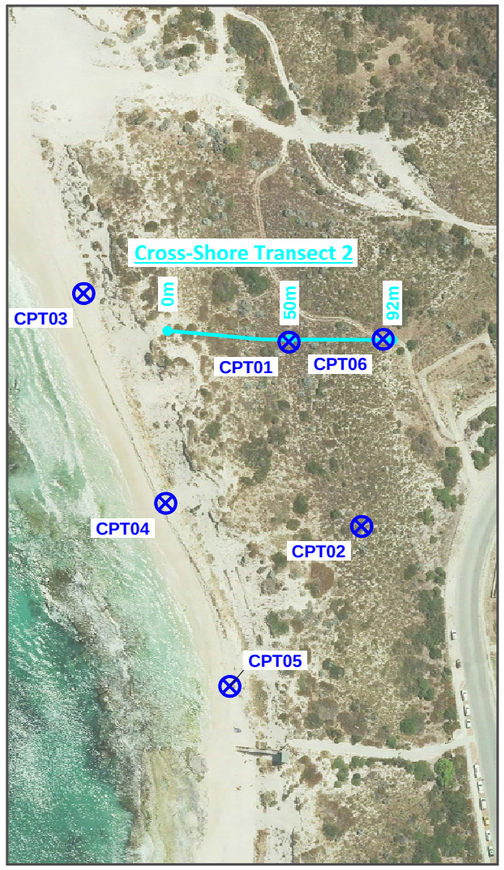
TWO ROCKS COASTAL VULNERABILITY STUDY, WESTERN AUSTRALIA

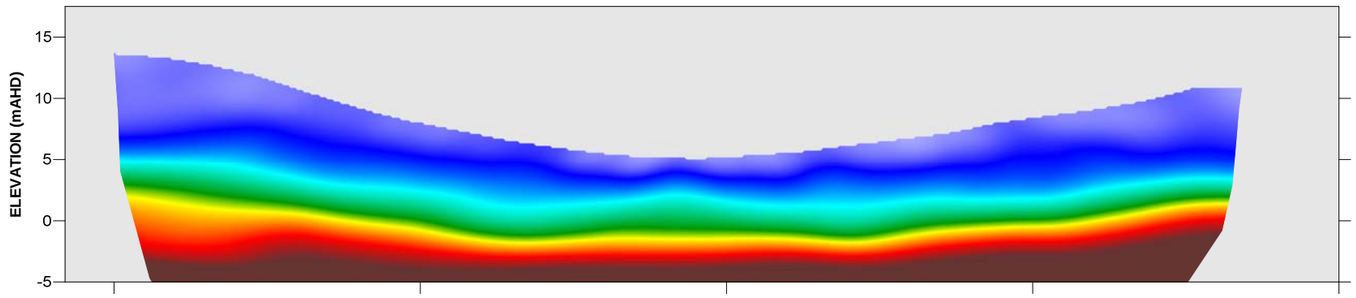
GEOPHYSICAL PROFILES AND CONE PENETROMETER TEST POINTS

Drawing No. 70345-04

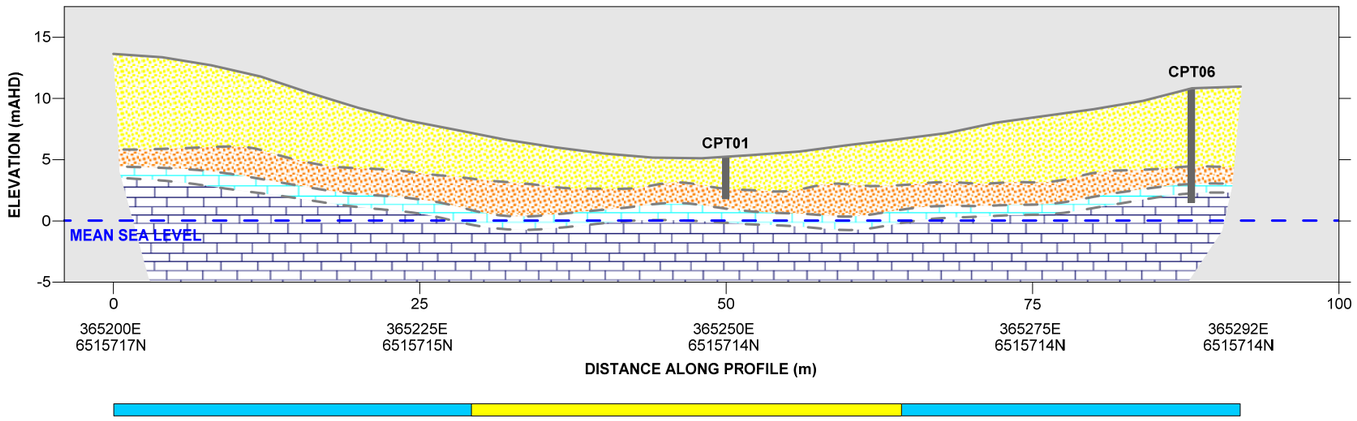
Elevation presented in mAHD is correct to +/- 0.25m



CROSS-SHORE TRANSECT 2 - SEISMIC P-WAVE VELOCITY SECTION

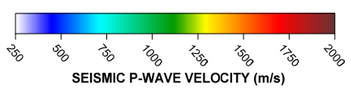


CROSS-SHORE TRANSECT 2 - INTERPRETED SECTION

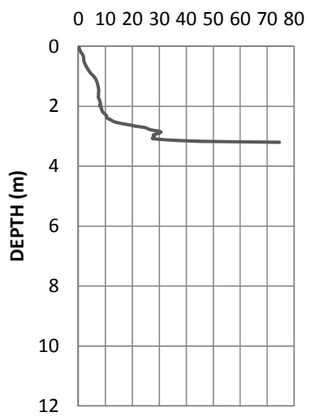


LEGEND

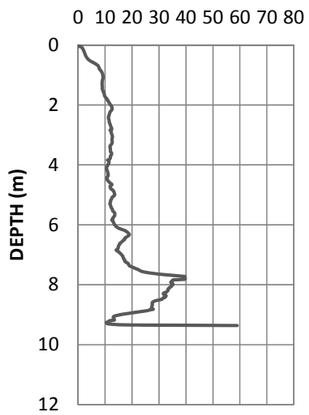
- SAND - LOW COMPACTION P-WAVE VELOCITY < 550 m/s
- SAND - MODERATE COMPACTION P-WAVE VELOCITY 550-800 m/s
- LIMESTONE - INTERPRETTED LOW TO MODERATE ROCK STRENGTH, P-WAVE VELOCITY 800-1000 m/s.
- LIMESTONE - INTERPRETED MODERATE ROCK STRENGTH, P-WAVE VELOCITY > 1000 m/s.
- MEAN SEA LEVEL WITHIN INTERPRETED MODERATE STRENGTH LIMESTONE
- MEAN SEA LEVEL WITHIN INTERPRETED SOFT/MODERATE STRENGTH LIMESTONE
- MEAN SEA LEVEL WITHIN INTERPRETED SAND

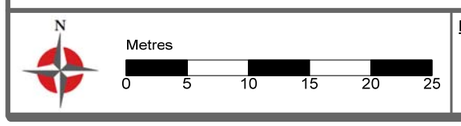


CPT01



CPT06





NOTES
Coordinates are in GDA94, MGA Zone 50.
Aerial image from Landgate February 2016
Drawing to be used in conjunction with report 70345, refer to report for investigation details, exclusions and limitations.

Date	10 August 2016	Paper Size	A3
Scale	1:500	Drawn	AHWS
Drawing	70345-04	Revision	A-1

CLIENT **DEPARTMENT OF TRANSPORT**

GEOPHYSICAL INFILL INVESTIGATION FOR COASTAL VULNERABILITY STUDY, TWO ROCKS WESTERN AUSTRALIA

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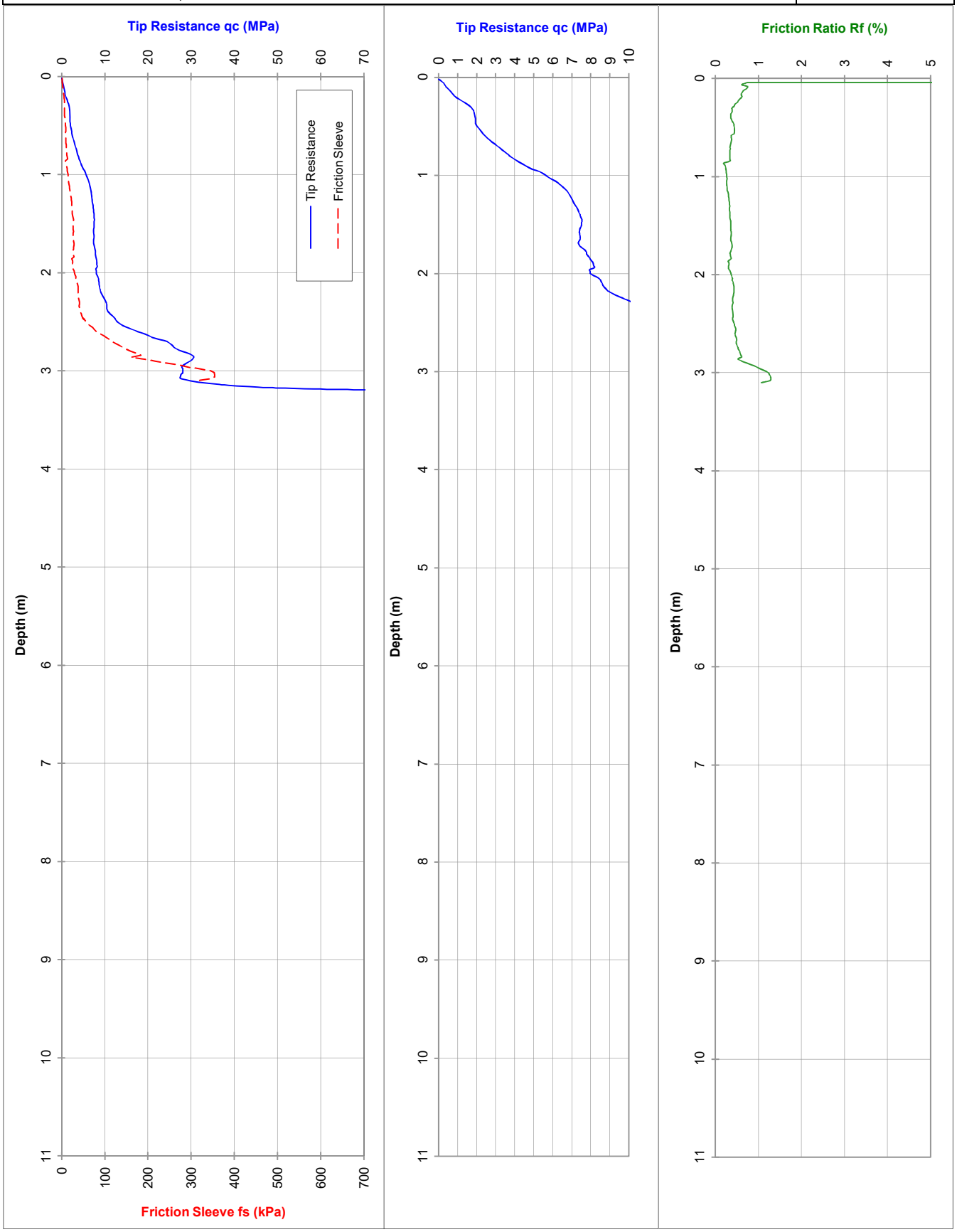
APPENDIX C.
CONE PENETROMETER TEST PLOTS

ELECTRIC FRICTION-CONE PENETROMETER

CLIENT: Department of Transport	Job No.: 70326	Probe I.D
PROJECT: Northern Two Rock Geophysical Surveying	RL (m):	**CPT 1**
LOCATION: Two Rocks, W.A.	Co-ords:	09-Aug-16



PROBEDRILL GEOTECHNICAL SURVEY

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

Approx. Water (m): Dry to 3.1

Dummy probe to (m):

Refusal: 90MPa

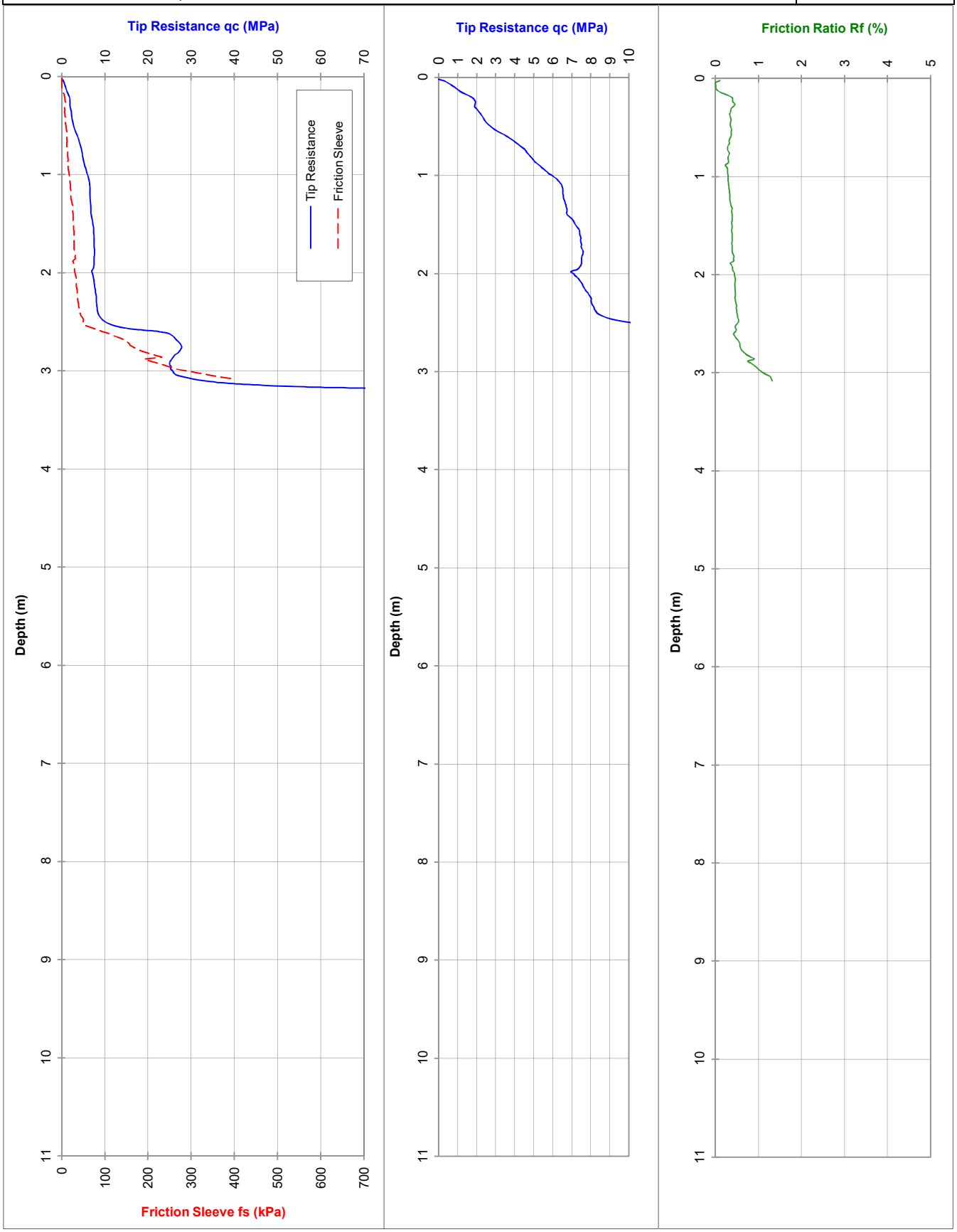
Cone I.D.: EC02

File: GB0051M

Rig Type: 12 tonne track rig (M1)

ELECTRIC FRICTION-CONE PENETROMETER

CLIENT: Department of Transport	Job No.: 70326	Probe I.D
PROJECT: Northern Two Rock Geophysical Surveying	RL (m):	**CPT 1A**
LOCATION: Two Rocks, W.A.	Co-ords:	09-Aug-16



PROBEDRILL GEOTECHNICAL SURVEY

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

Approx. Water (m): Dry to 3.1

Dummy probe to (m):

Refusal: 90MPa

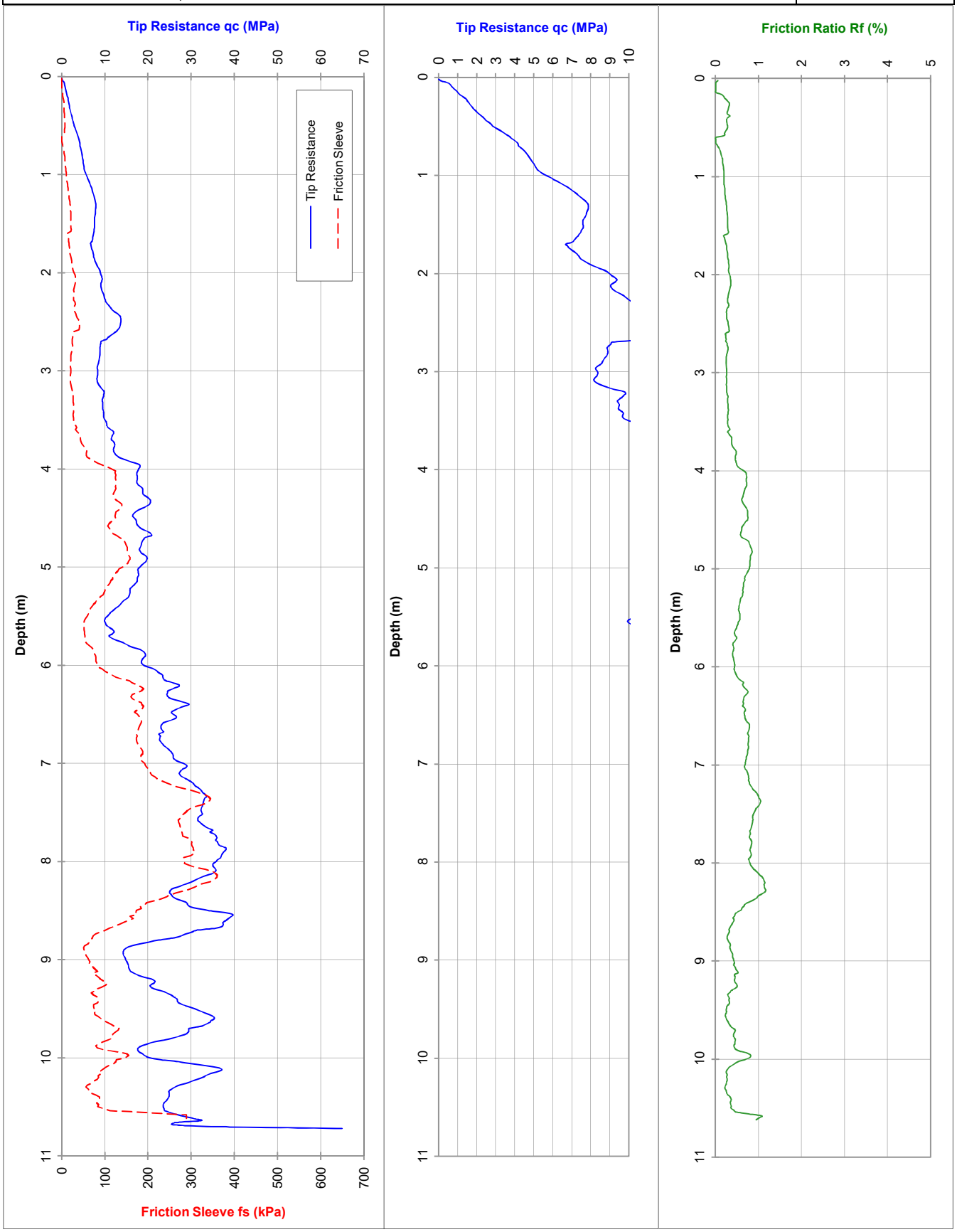
Cone I.D.: EC02

File: GB0052M

Rig Type: 12 tonne track rig (M1)

ELECTRIC FRICTION-CONE PENETROMETER

CLIENT: Department of Transport	Job No.: 70326	Probe I.D
PROJECT: Northern Two Rock Geophysical Surveying	RL (m):	**CPT 2**
LOCATION: Two Rocks, W.A.	Co-ords:	09-Aug-16



PROBEDRILL GEOTECHNICAL SURVEY

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

Approx. Water (m): Dry to 9.0

Dummy probe to (m):

Refusal: 65MPa + Lat. Rod Support

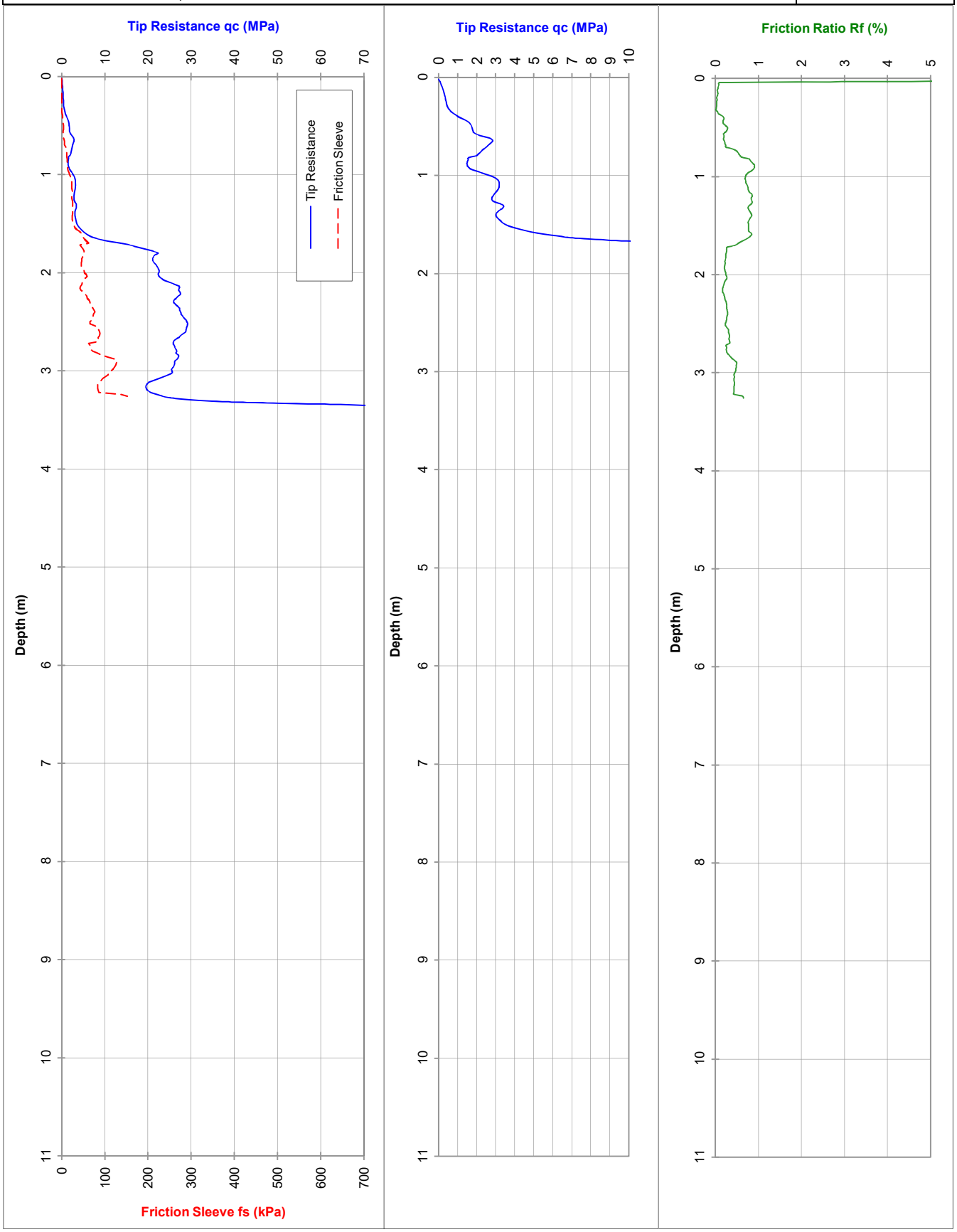
Cone I.D.: EC02

File: GB0053M

Rig Type: 12 tonne track rig (M1)

ELECTRIC FRICTION-CONE PENETROMETER

CLIENT: Department of Transport	Job No.: 70326	Probe I.D
PROJECT: Northern Two Rock Geophysical Surveying	RL (m):	**CPT 3**
LOCATION: Two Rocks, W.A.	Co-ords:	09-Aug-16



PROBEDRILL GEOTECHNICAL SURVEY

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

Approx. Water (m): 1.9

Dummy probe to (m):

Refusal: 80MPa

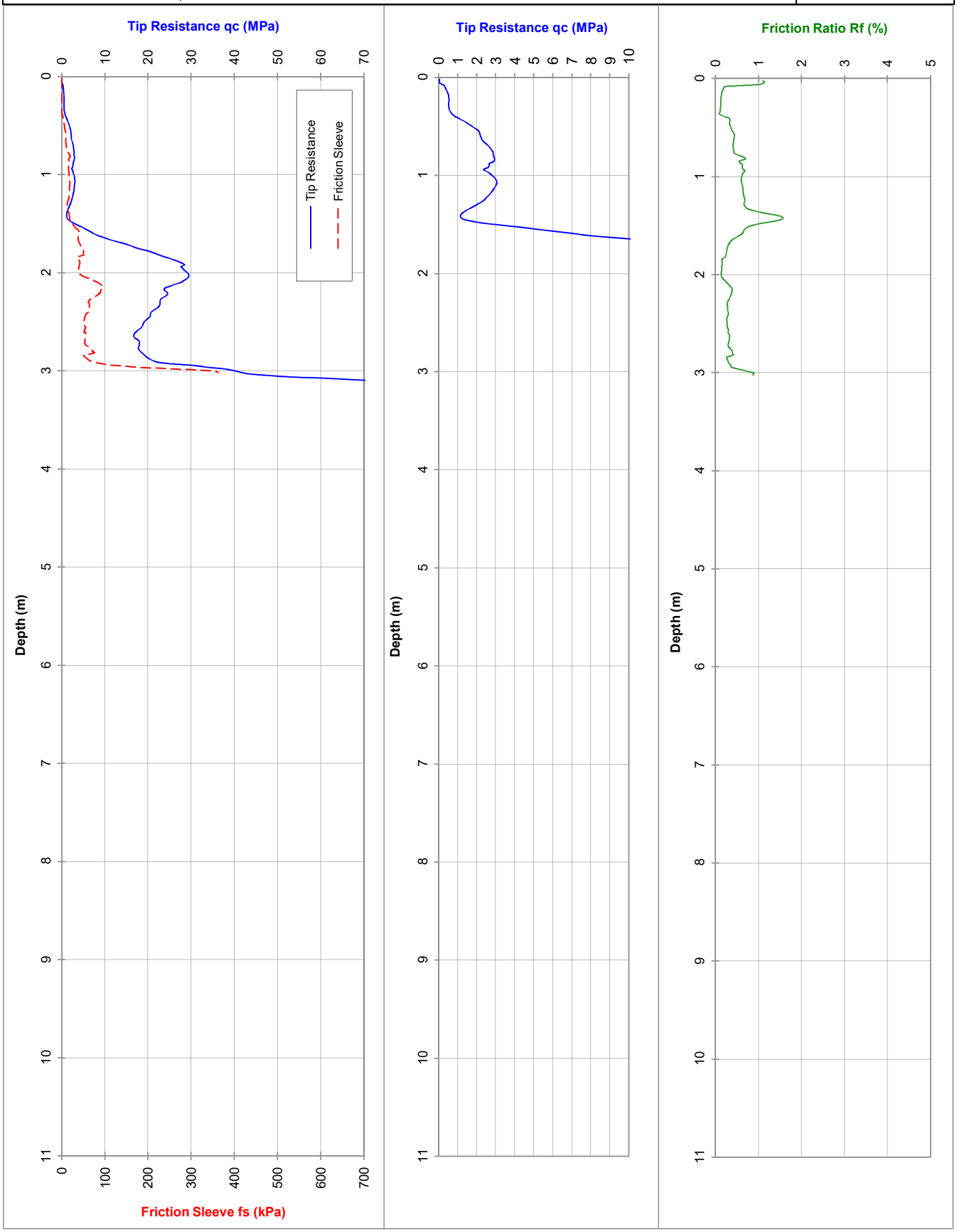
Cone I.D.: EC02

File: GB0054M

Rig Type: 12 tonne track rig (M1)

ELECTRIC FRICTION-CONE PENETROMETER

CLIENT: Department of Transport	Job No.: 70326	Probe I.D
PROJECT: Northern Two Rock Geophysical Surveying	RL (m):	**CPT 4**
LOCATION: Two Rocks, W.A.	Co-ords:	09-Aug-16



PROBEDRILL GEOTECHNICAL SURVEY

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

Approx. Water (m): 1.3

Dummy probe to (m):

Refusal: 85MPa

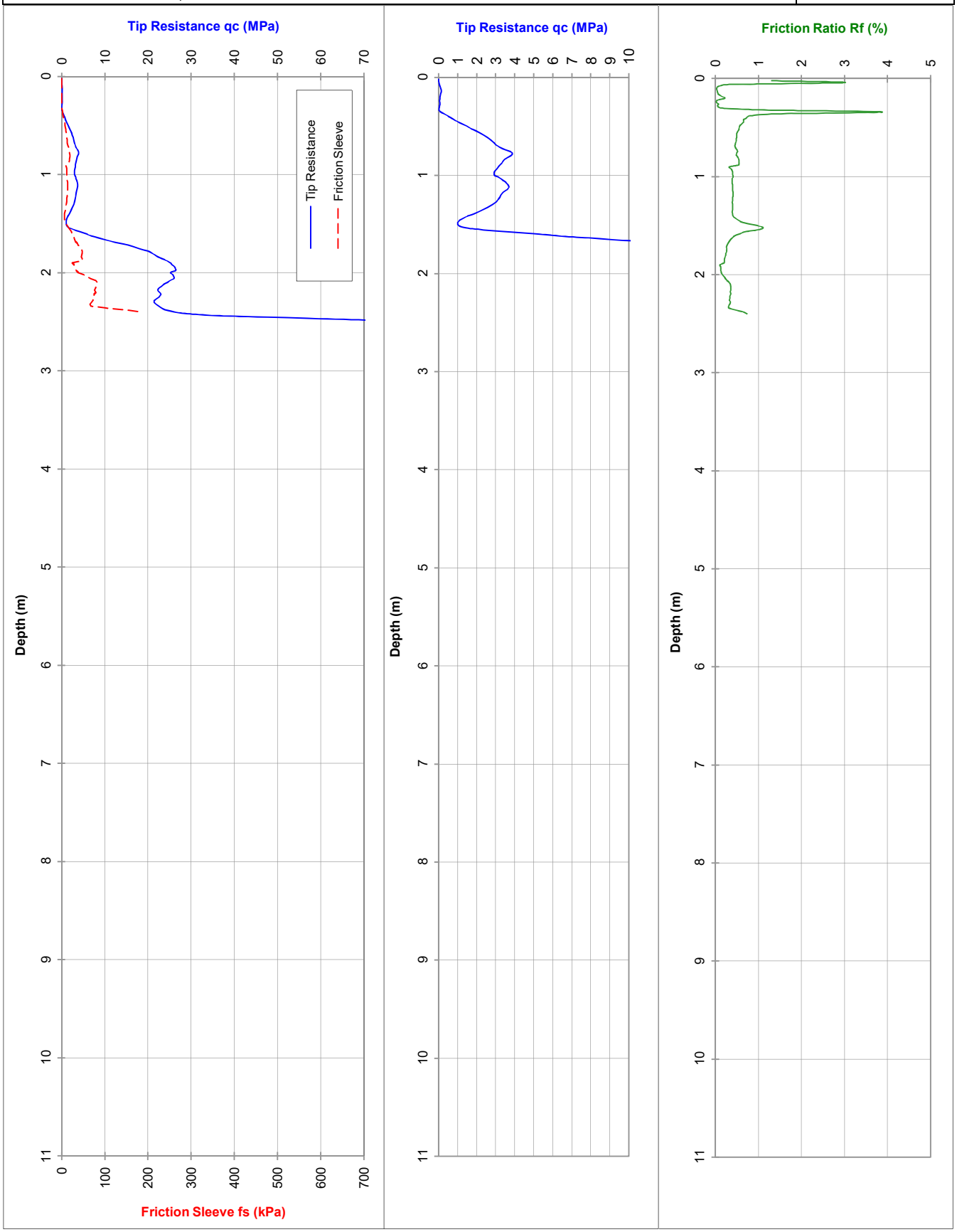
Cone I.D.: EC02

File: GB0056M

Rig Type: 12 tonne track rig (M1)

ELECTRIC FRICTION-CONE PENETROMETER

CLIENT: Department of Transport	Job No.: 70326	Probe I.D
PROJECT: Northern Two Rock Geophysical Surveying	RL (m):	**CPT 4A**
LOCATION: Two Rocks, W.A.	Co-ords:	09-Aug-16



PROBEDRILL GEOTECHNICAL SURVEY

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

Approx. Water (m): 1.1

Dummy probe to (m):

Refusal: 90MPa

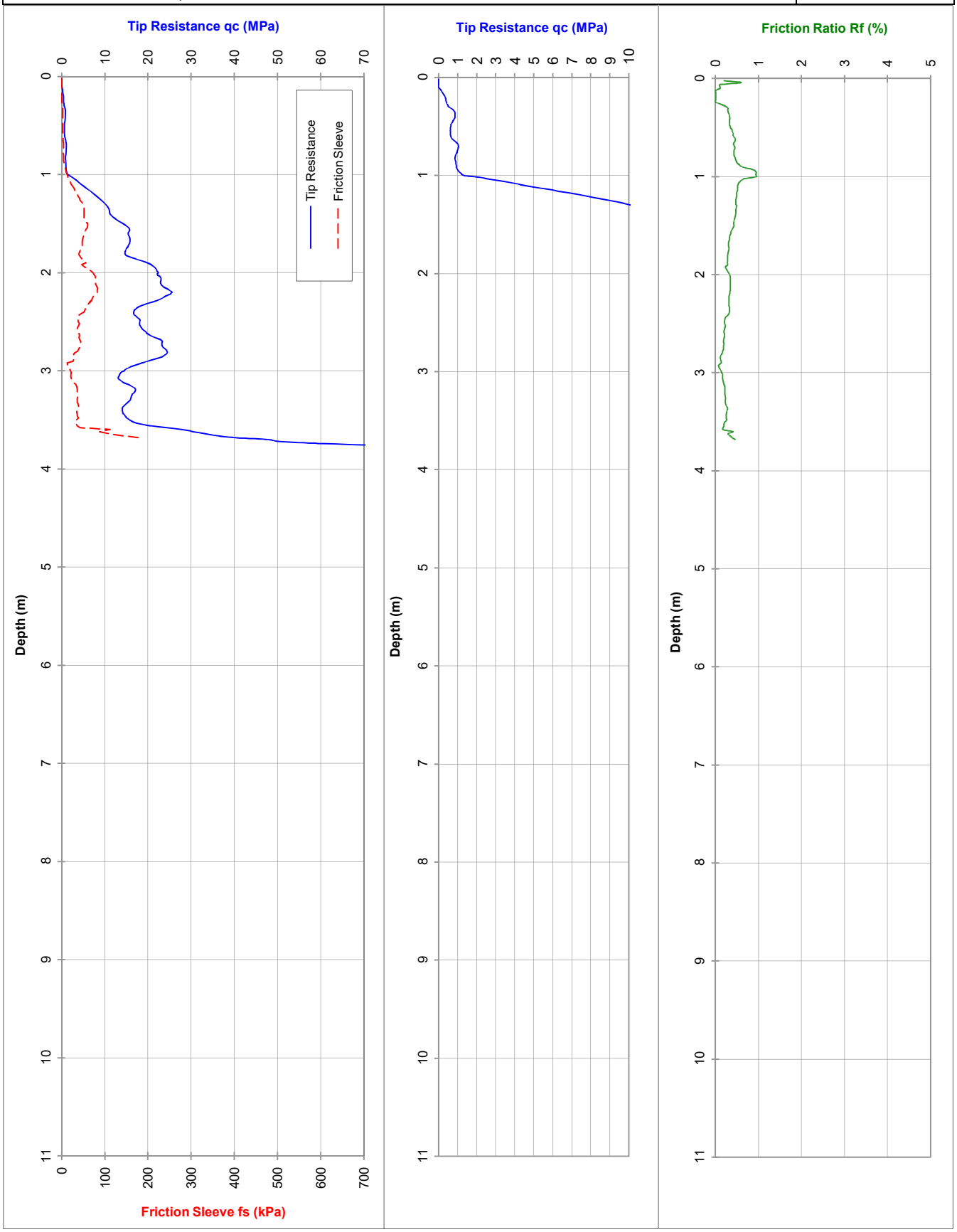
Cone I.D.: EC02

File: GB0057M

Rig Type: 12 tonne track rig (M1)

ELECTRIC FRICTION-CONE PENETROMETER

CLIENT: Department of Transport	Job No.: 70326	Probe I.D
PROJECT: Northern Two Rock Geophysical Surveying	RL (m):	**CPT 5**
LOCATION: Two Rocks, W.A.	Co-ords:	09-Aug-16



PROBEDRILL GEOTECHNICAL SURVEY

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

Approx. Water (m): 1.4

Dummy probe to (m):

Refusal: 80MPa

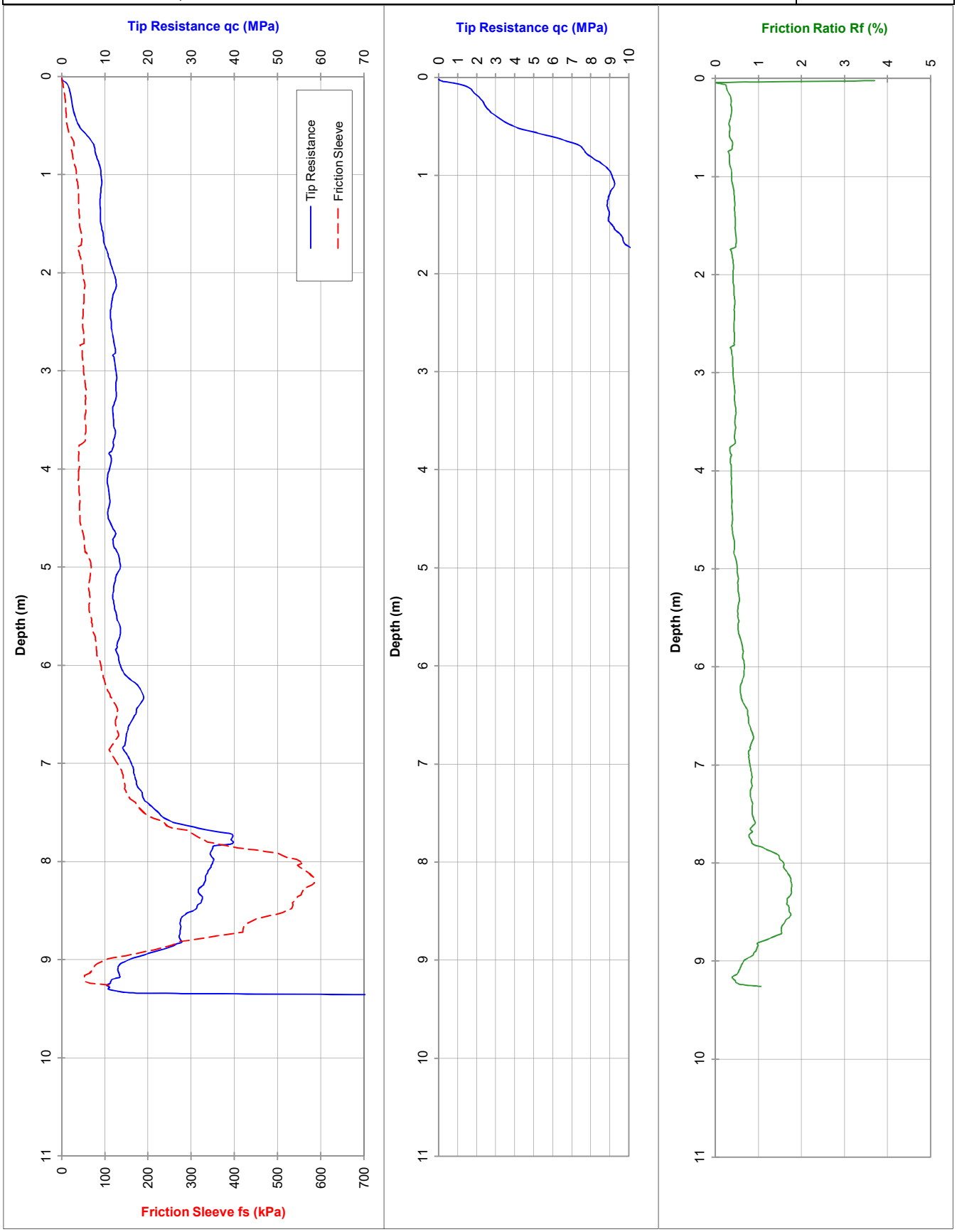
Cone I.D.: EC02

File: GB0058M

Rig Type: 12 tonne track rig (M1)

ELECTRIC FRICTION-CONE PENETROMETER

CLIENT: Department of Transport	Job No.: 70326	Probe I.D
PROJECT: Northern Two Rock Geophysical Surveying	RL (m):	**CPT 6**
LOCATION: Two Rocks, W.A.	Co-ords:	09-Aug-16



PROBEDRILL GEOTECHNICAL SURVEY

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

Approx. Water (m): Dry to 9.0

Dummy probe to (m):

Refusal: 90MPa

Cone I.D.: EC02

File: GB0059M

Rig Type: 12 tonne track rig (M1)

PROBEDRILL
GEOTECHNICAL SURVEY

CALIBRATION CERTIFICATE (qc & fs)

CONE ID: EC02

Cone Capacity: qc - 100MPa, fs - 2000kPa
Calibration Date: 9 June 2016
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 22/03/16 - NATA approved Cert. No. 160447)

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 repeclively.

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	0.76	10.03	0.30	0.26	1
20.0	1.51	19.99	-0.03	0.00	1
30.0	2.27	30.00	-0.01	0.13	1
40.0	3.02	39.97	-0.08	0.07	1
50.0	3.78	49.98	-0.04	0.08	1
60.0	4.54	59.99	-0.02	0.02	1
70.0	5.29	69.97	-0.04	0.04	1
80.0	6.05	79.99	-0.02	0.07	1
90.0	6.81	90.00	0.00	0.01	1
100.0	7.57	100.06	0.06	0.05	1
90.0	6.82	89.85	-0.16	0.07	1
80.0	6.07	79.96	-0.06	0.07	1
70.0	5.32	70.03	0.04	0.11	1
60.0	4.57	60.08	0.14	0.09	1
50.0	3.81	50.07	0.15	0.18	1
40.0	3.05	40.08	0.20	0.20	1
30.0	2.29	30.07	0.24	0.26	1
20.0	1.53	20.04	0.21	0.33	1
10.0	0.77	10.01	0.13	0.65	1
0.0	0.00	0.00	0.00	0.00	1

R^2 Value = 1.0000

qc Calibration Factor (MPa/Volt): 13.21

"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	-0.45	0.14	1
6.0	1.49	399	-0.22	0.13	1
9.0	2.24	600	-0.02	0.13	1
12.0	2.99	800	-0.03	0.10	1
15.0	3.74	1000	-0.03	0.16	1
18.0	4.49	1200	-0.02	0.09	1
21.0	5.25	1400	-0.01	0.02	1
24.0	6.00	1600	0.02	0.03	1
27.0	6.75	1800	-0.01	0.06	1
30.0	7.50	2001	0.04	0.03	1
27.0	6.73	1798	-0.20	0.01	1
24.0	5.99	1600	-0.01	0.03	1
21.0	5.24	1401	0.06	0.06	1
18.0	4.49	1201	0.08	0.09	1
15.0	3.75	1002	0.15	0.05	1
12.0	2.99	801	0.09	0.07	1
9.0	2.24	600	-0.03	0.18	1
6.0	1.48	398	-0.52	0.13	1
3.0	0.74	198	-0.91	0.27	1
0.0	0.00	0	0.00	0.00	1

R^2 Value = 1.0000

fs Calibration Factor (kPa/volt): 266.73

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

Calibration Checked & Authorised: Brett Edwards

Job Details

Client:	GBG Maps	**Date of Job:**	9/8/16
Rep:	Andrew Spyrou	**Tip Diameter:**	35.51
Location:	Two Rocks	**Sleeve Diameter:**	36.09

APPENDIX D.
RESULTS COMBINED WITH PREVIOUS SURVEYS

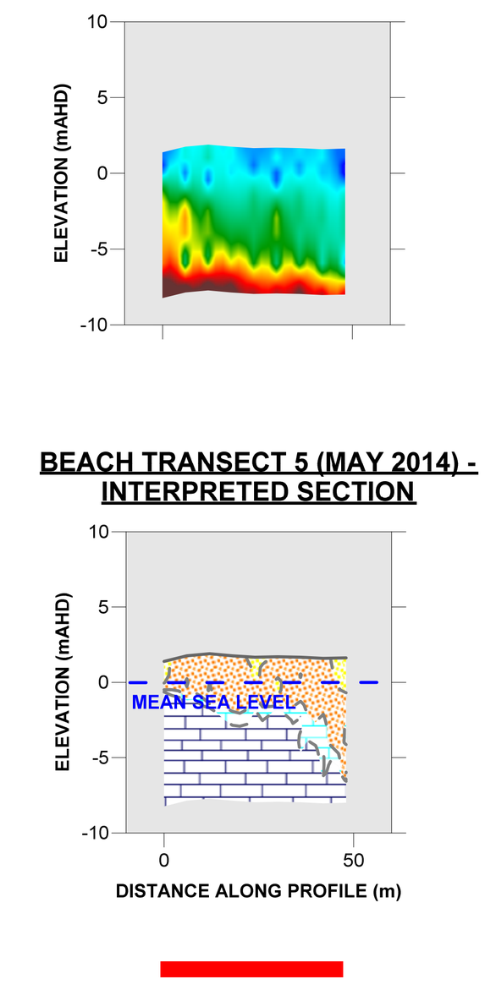
GBGMAPS
Advanced Subsurface Investigations

TWO ROCKS COASTAL VULNERABILITY STUDY, WESTERN AUSTRALIA

COMBINED INVESTIGATION RESULTS - SOUTHERN (MAY 2014), NORTHERN (MARCH 2016) AND INFILL (AUGUST 2016)

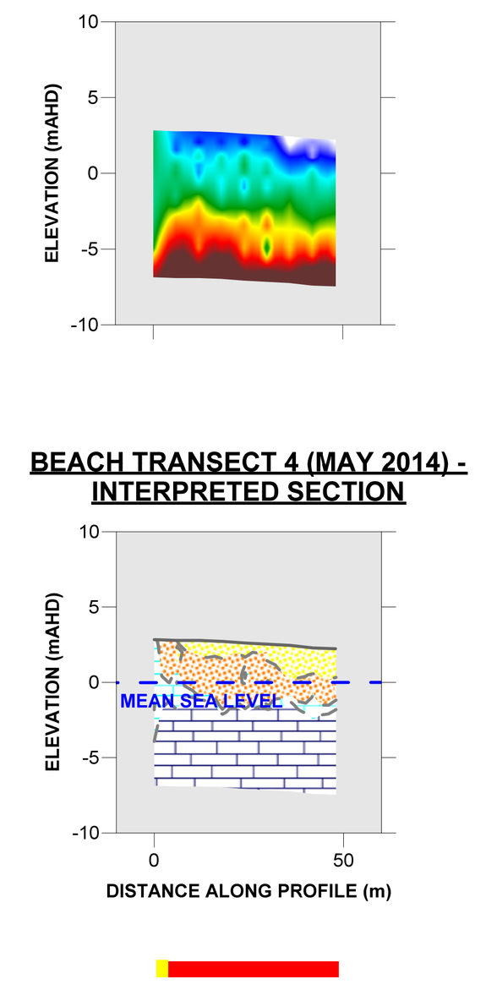
BEACH TRANSECT 5 (MAY 2014) - SEISMIC S-WAVE VELOCITY SECTION

BEACH TRANSECT 5 (MAY 2014) - INTERPRETED SECTION



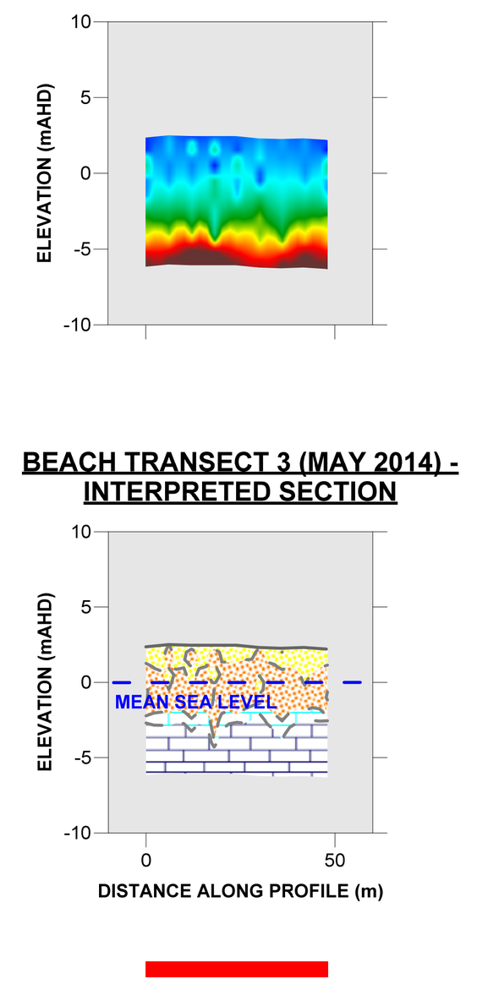
BEACH TRANSECT 4 (MAY 2014) - SEISMIC S-WAVE VELOCITY SECTION

BEACH TRANSECT 4 (MAY 2014) - INTERPRETED SECTION



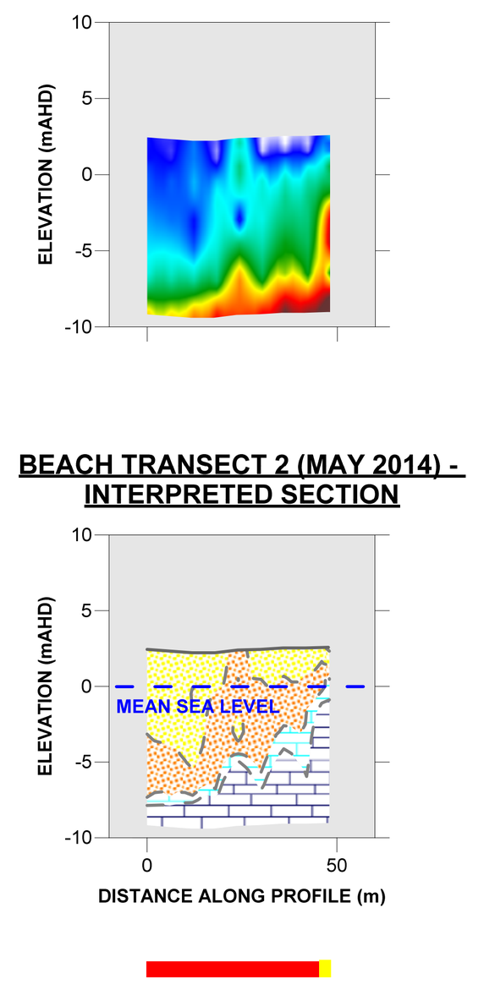
BEACH TRANSECT 3 (MAY 2014) - SEISMIC S-WAVE VELOCITY SECTION

BEACH TRANSECT 3 (MAY 2014) - INTERPRETED SECTION



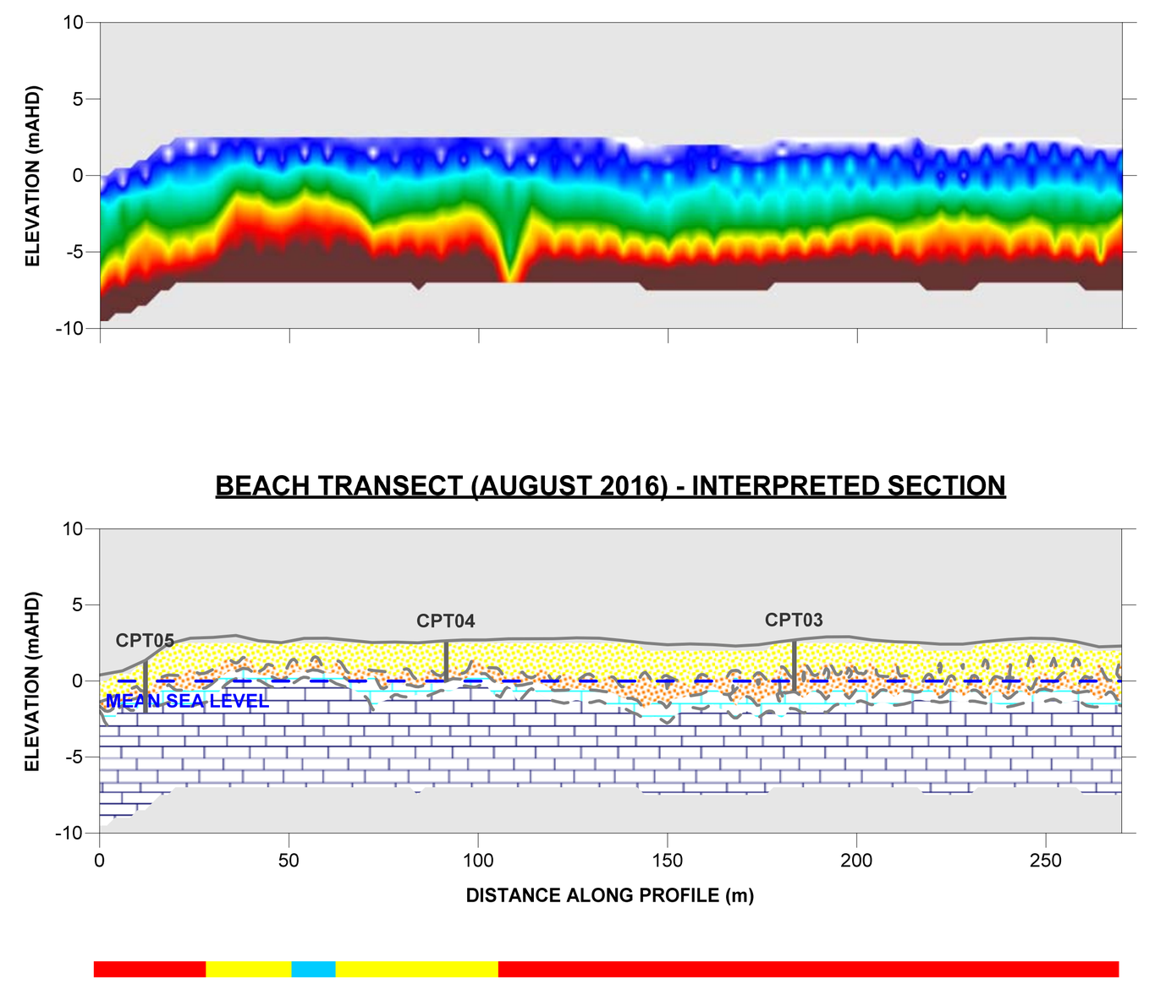
BEACH TRANSECT 2 (MAY 2014) - SEISMIC S-WAVE VELOCITY SECTION

BEACH TRANSECT 2 (MAY 2014) - INTERPRETED SECTION



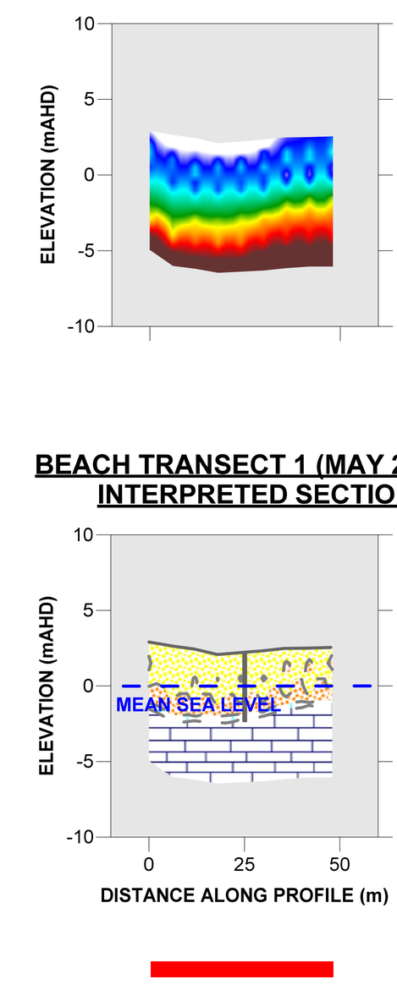
BEACH TRANSECT (AUGUST 2016) - SEISMIC S-WAVE VELOCITY SECTION

BEACH TRANSECT (AUGUST 2016) - INTERPRETED SECTION



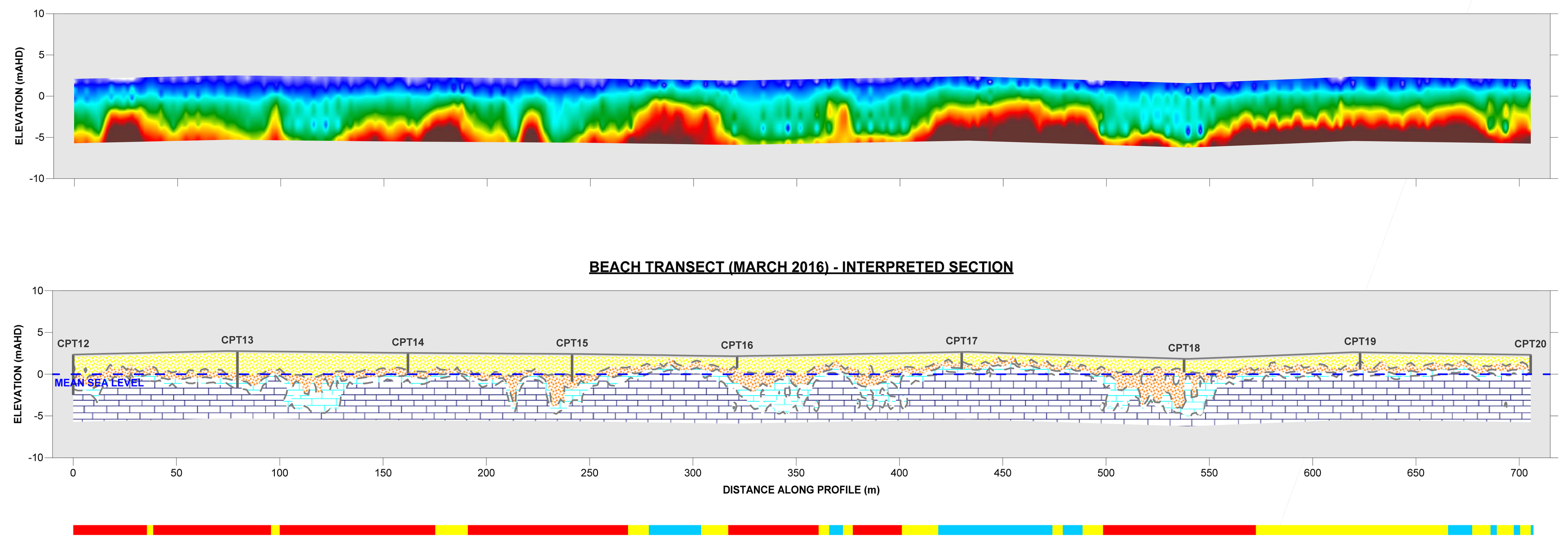
BEACH TRANSECT 1 (MAY 2014) - SEISMIC S-WAVE VELOCITY SECTION

BEACH TRANSECT 1 (MAY 2014) - INTERPRETED SECTION



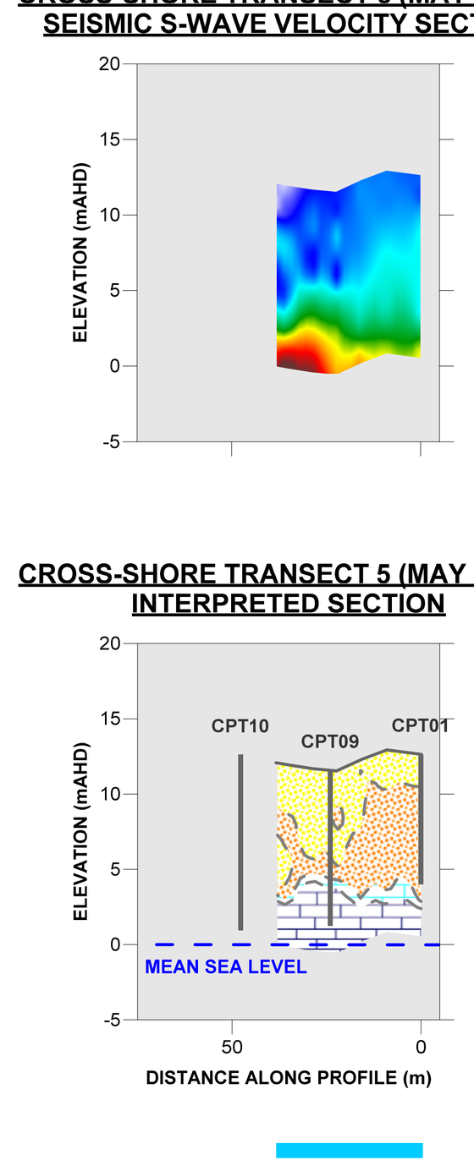
BEACH TRANSECT (MARCH 2016) - SEISMIC S-WAVE VELOCITY SECTION

BEACH TRANSECT (MARCH 2016) - INTERPRETED SECTION



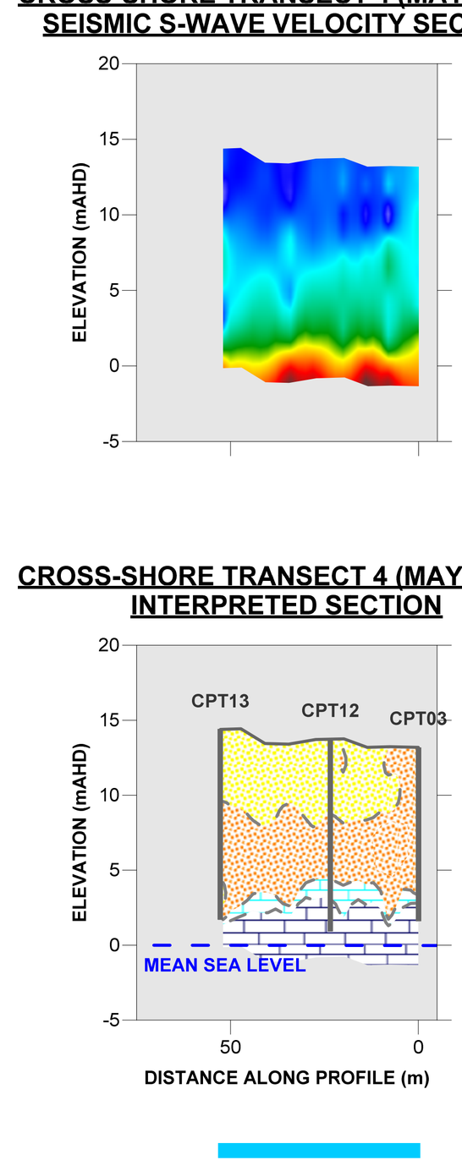
CROSS-SHORE TRANSECT 5 (MAY 2014) - SEISMIC S-WAVE VELOCITY SECTION

CROSS-SHORE TRANSECT 5 (MAY 2014) - INTERPRETED SECTION



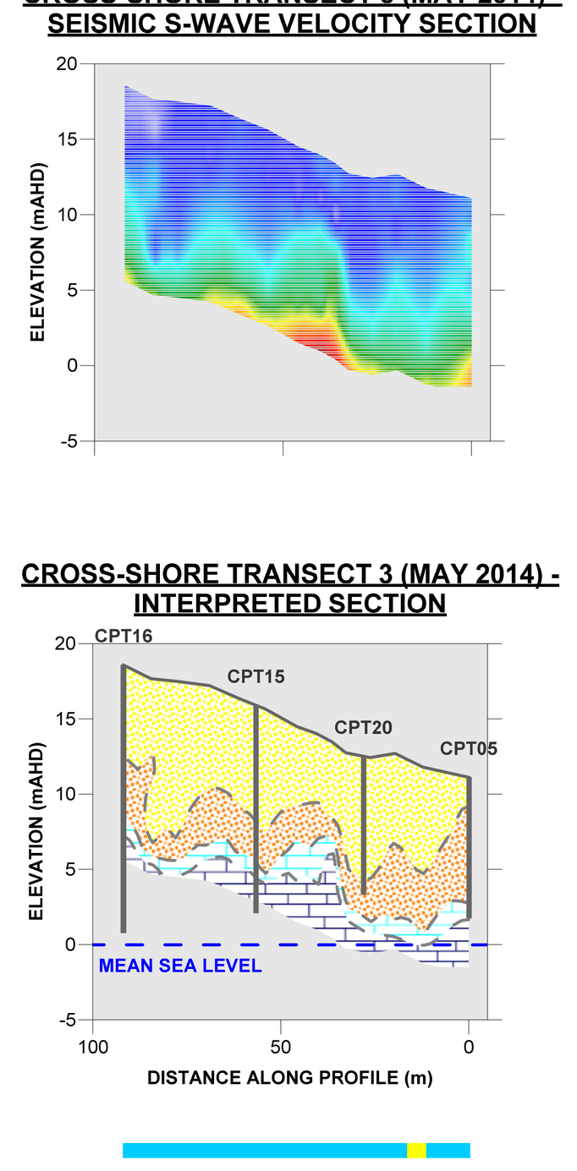
CROSS-SHORE TRANSECT 4 (MAY 2014) - SEISMIC S-WAVE VELOCITY SECTION

CROSS-SHORE TRANSECT 4 (MAY 2014) - INTERPRETED SECTION



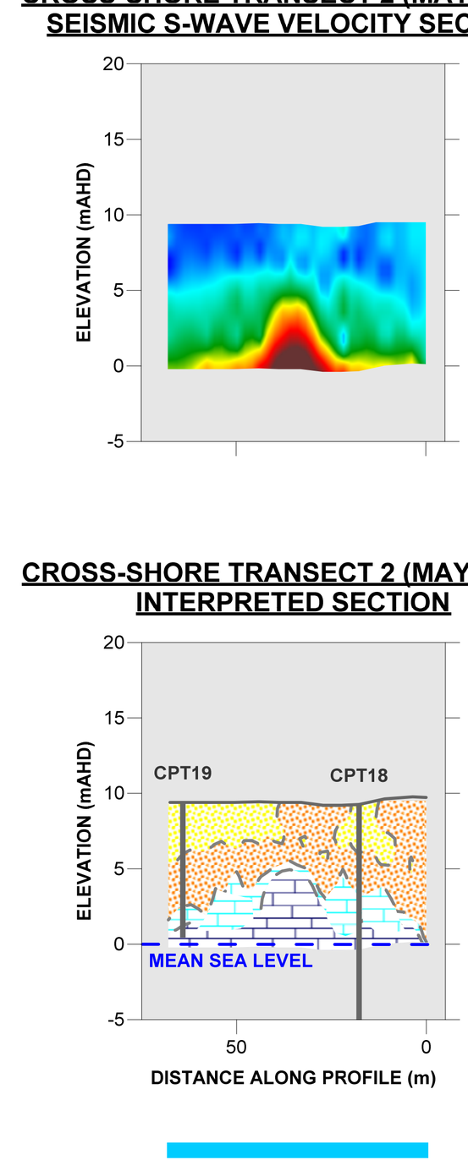
CROSS-SHORE TRANSECT 3 (MAY 2014) - SEISMIC S-WAVE VELOCITY SECTION

CROSS-SHORE TRANSECT 3 (MAY 2014) - INTERPRETED SECTION



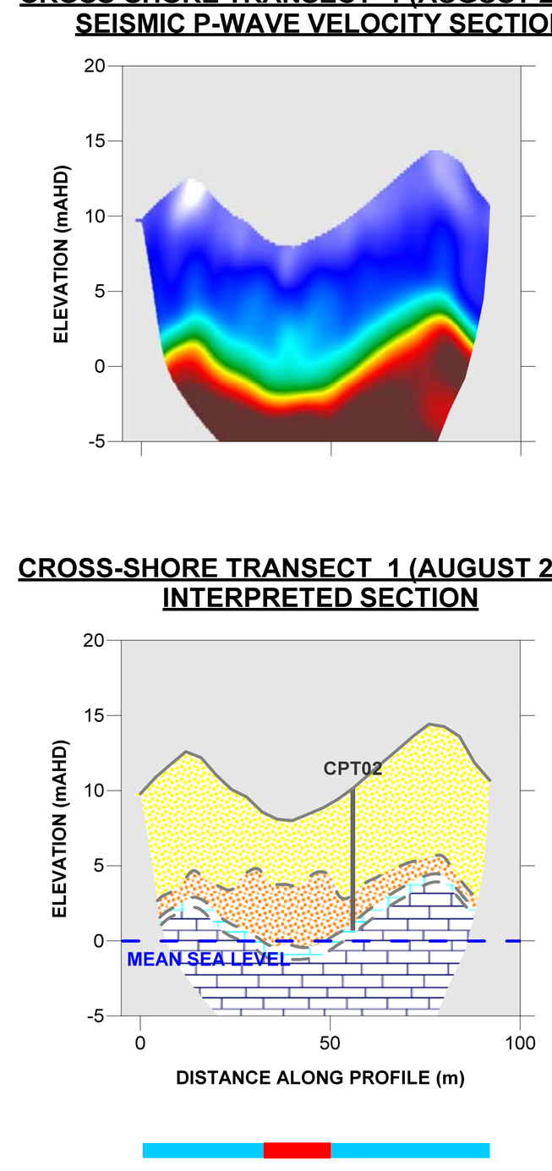
CROSS-SHORE TRANSECT 2 (MAY 2014) - SEISMIC S-WAVE VELOCITY SECTION

CROSS-SHORE TRANSECT 2 (MAY 2014) - INTERPRETED SECTION



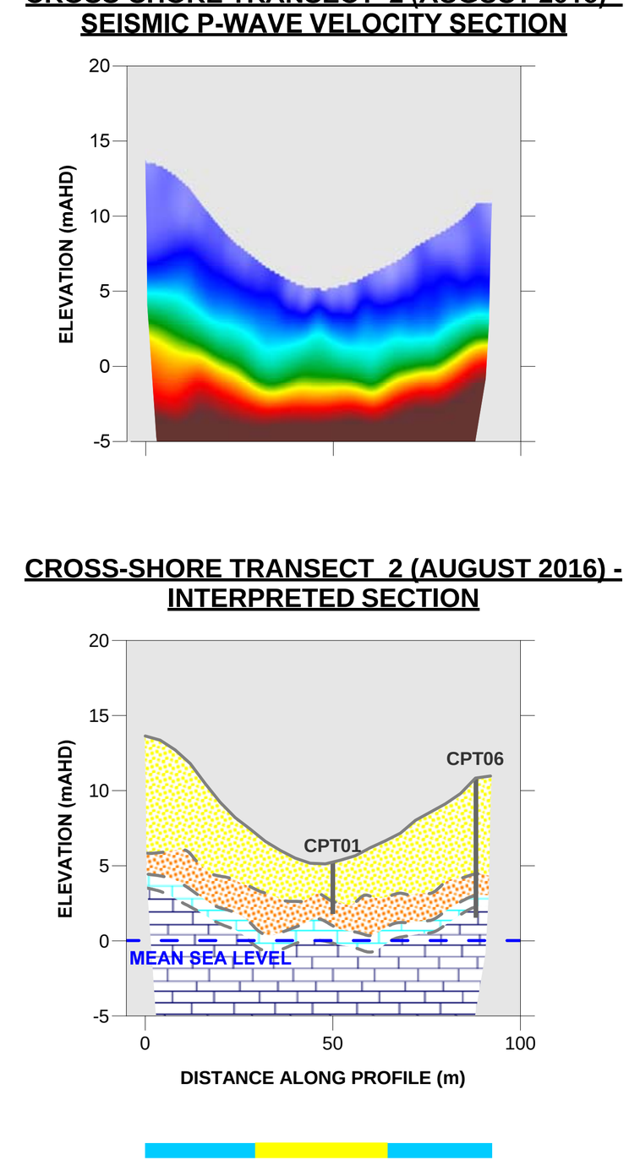
CROSS-SHORE TRANSECT 1 (AUGUST 2016) - SEISMIC P-WAVE VELOCITY SECTION

CROSS-SHORE TRANSECT 1 (AUGUST 2016) - INTERPRETED SECTION



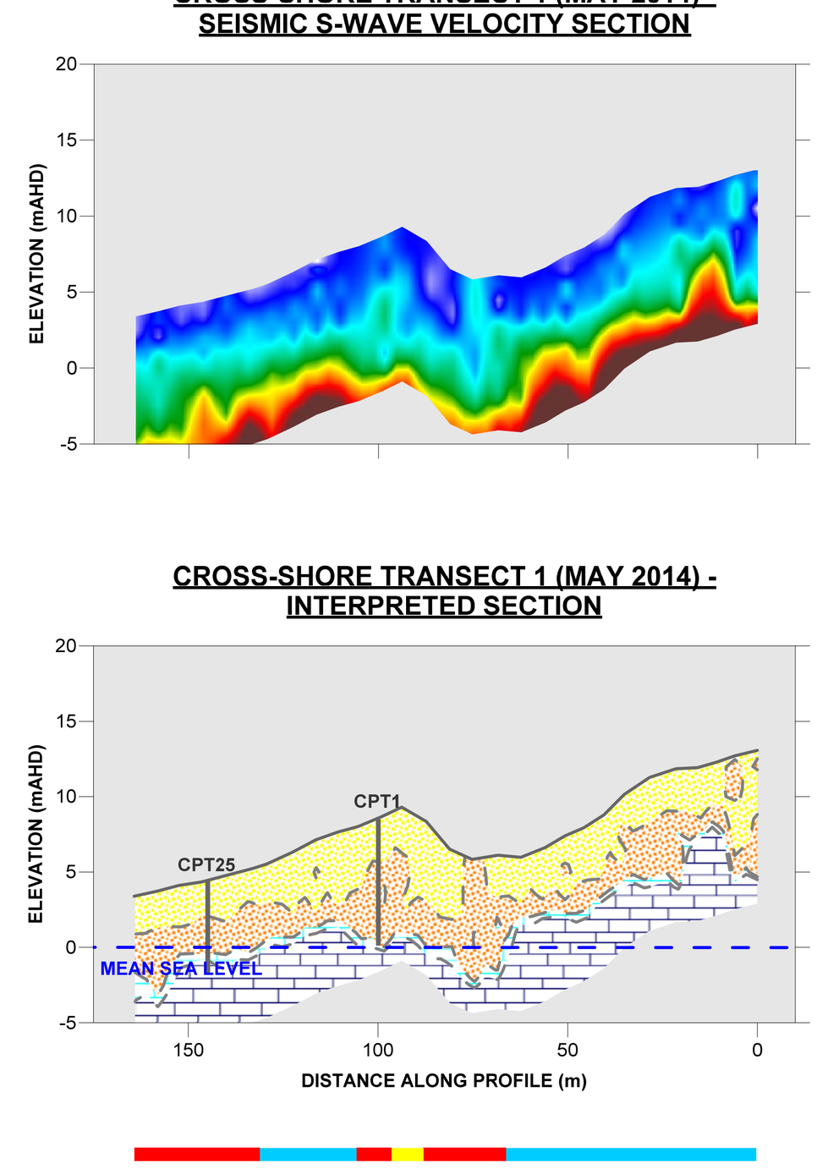
CROSS-SHORE TRANSECT 2 (AUGUST 2016) - SEISMIC P-WAVE VELOCITY SECTION

CROSS-SHORE TRANSECT 2 (AUGUST 2016) - INTERPRETED SECTION



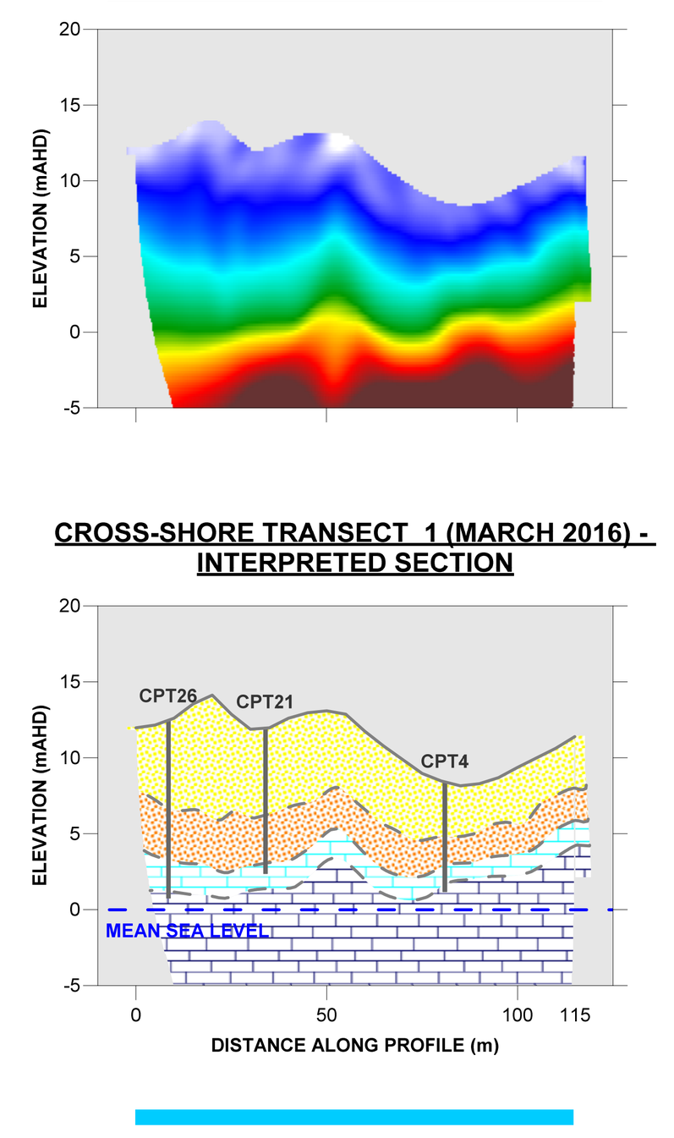
CROSS-SHORE TRANSECT 1 (MAY 2014) - SEISMIC S-WAVE VELOCITY SECTION

CROSS-SHORE TRANSECT 1 (MAY 2014) - INTERPRETED SECTION



CROSS-SHORE TRANSECT 1 (MARCH 2016) - SEISMIC P-WAVE VELOCITY SECTION

CROSS-SHORE TRANSECT 1 (MARCH 2016) - INTERPRETED SECTION



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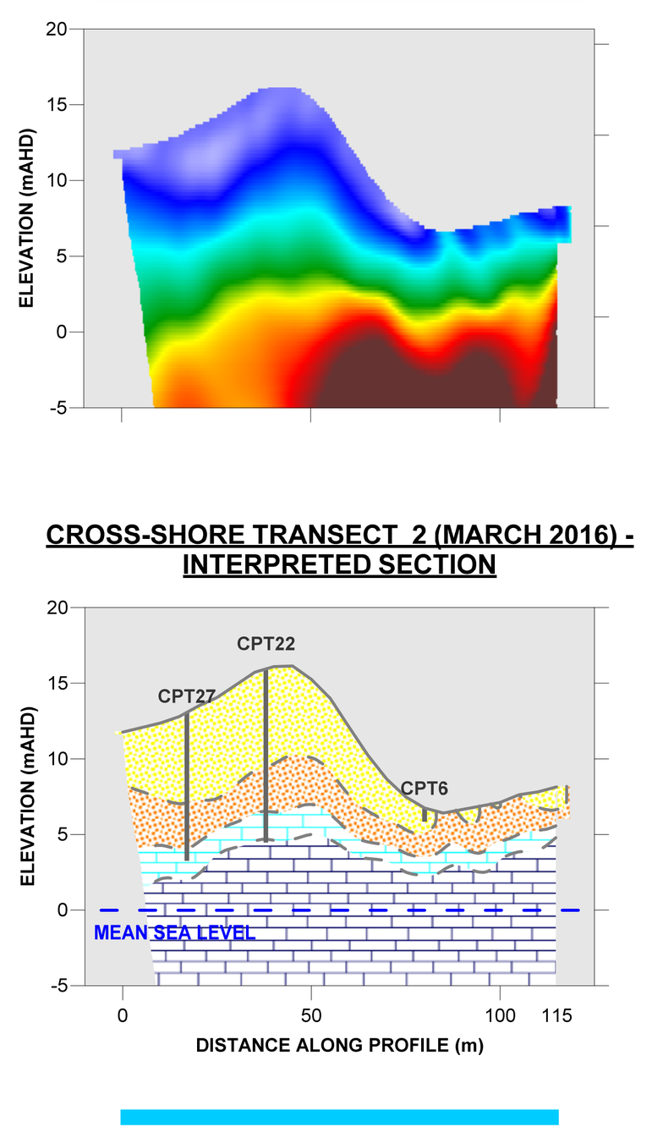
CROSS-SHORE TRANSECT 2 (MARCH 2016) - INTERPRETED SECTION



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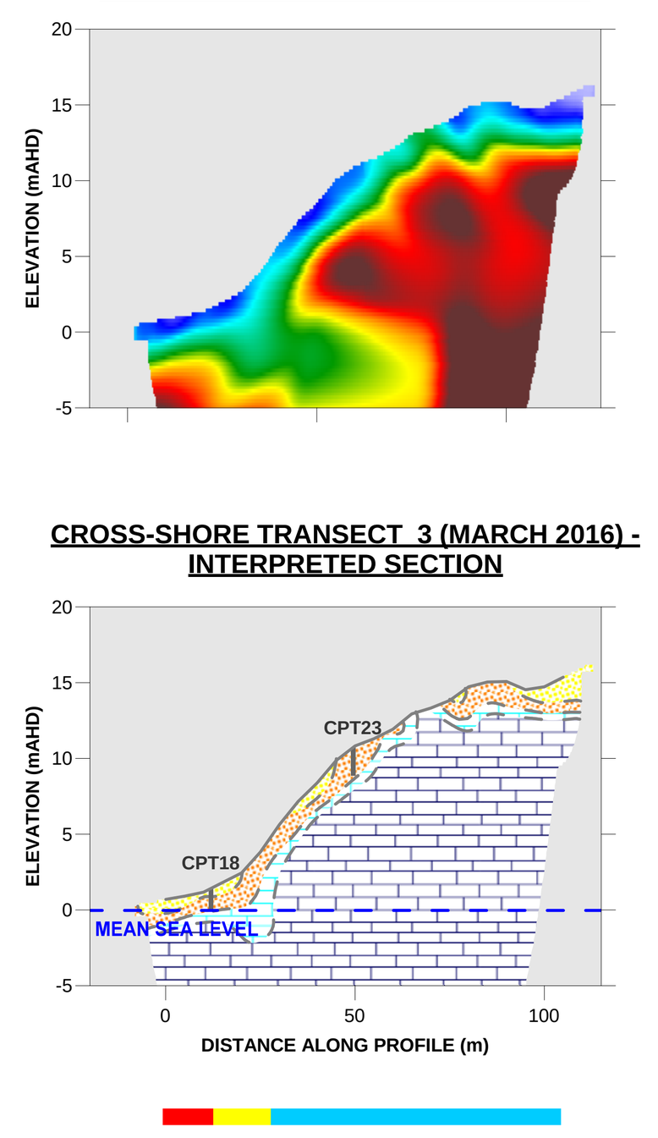
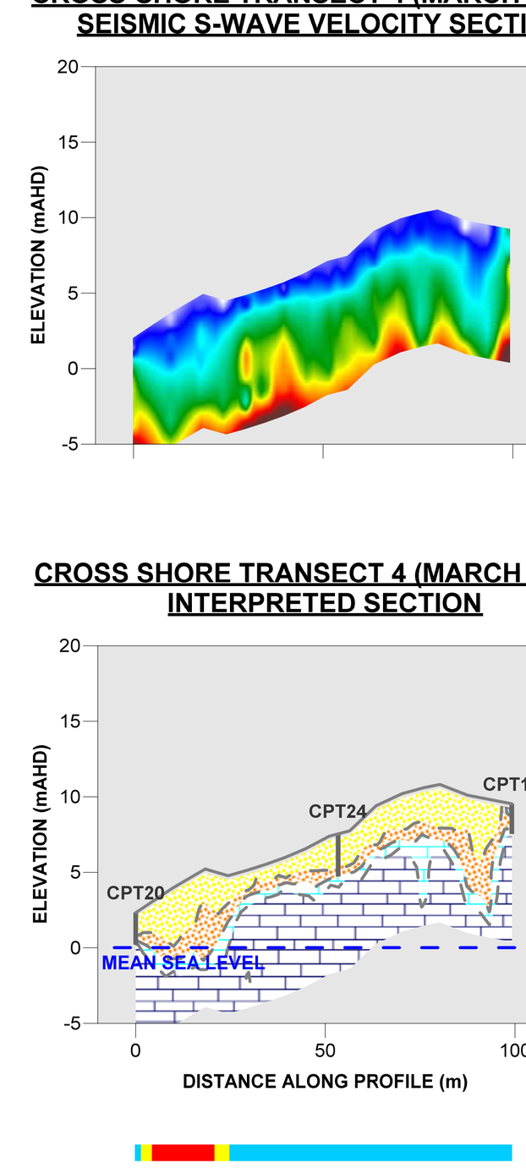
CROSS-SHORE TRANSECT 3 (MARCH 2016) - INTERPRETED SECTION



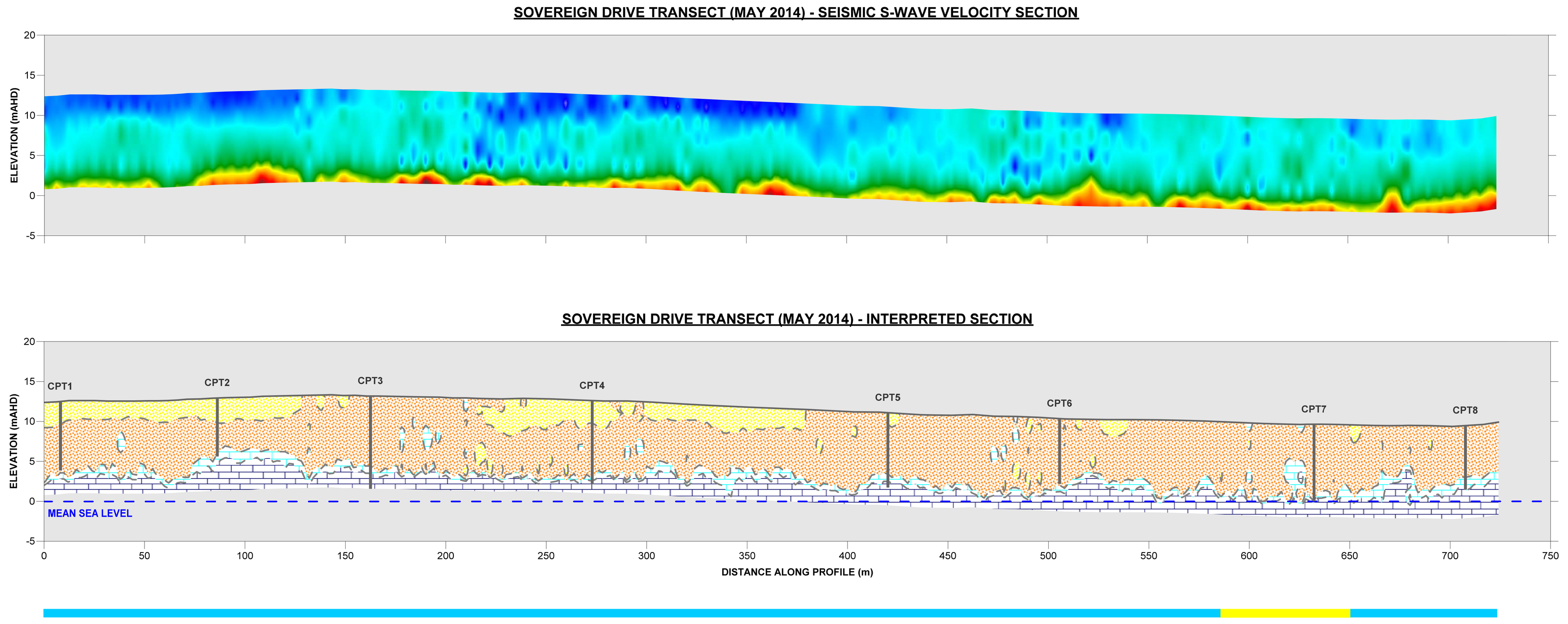
CROSS-SHORE TRANSECT 4 (MARCH 2016) - SEISMIC S-WAVE VELOCITY SECTION

CROSS SHORE TRANSECT 4 (MARCH 2016) - INTERPRETED SECTION



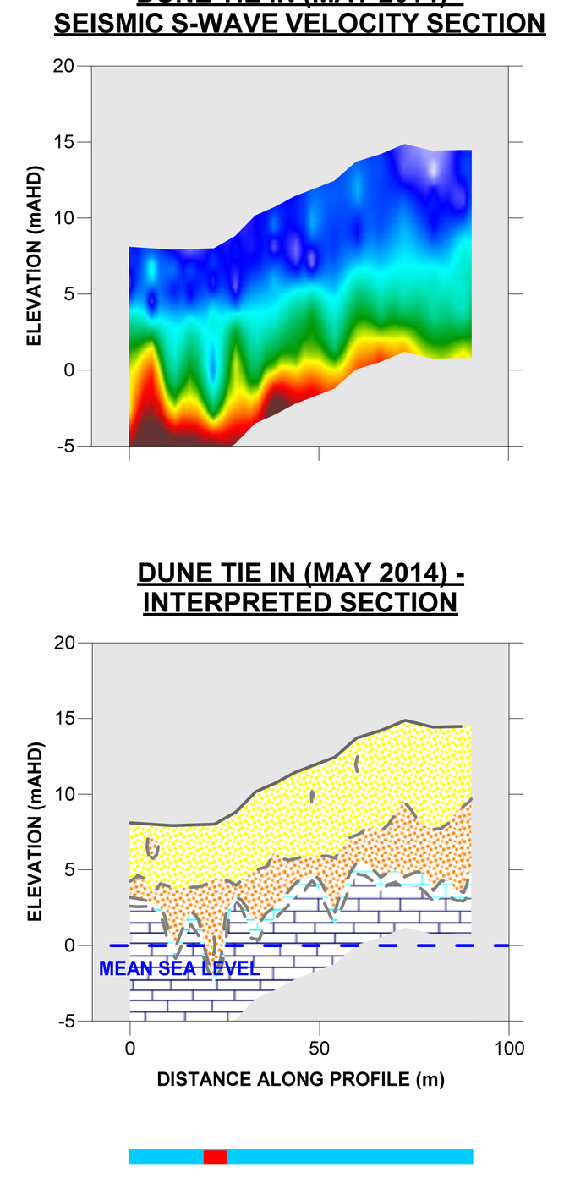
SOVEREIGN DRIVE TRANSECT (MAY 2014) - SEISMIC S-WAVE VELOCITY SECTION

SOVEREIGN DRIVE TRANSECT (MAY 2014) - INTERPRETED SECTION



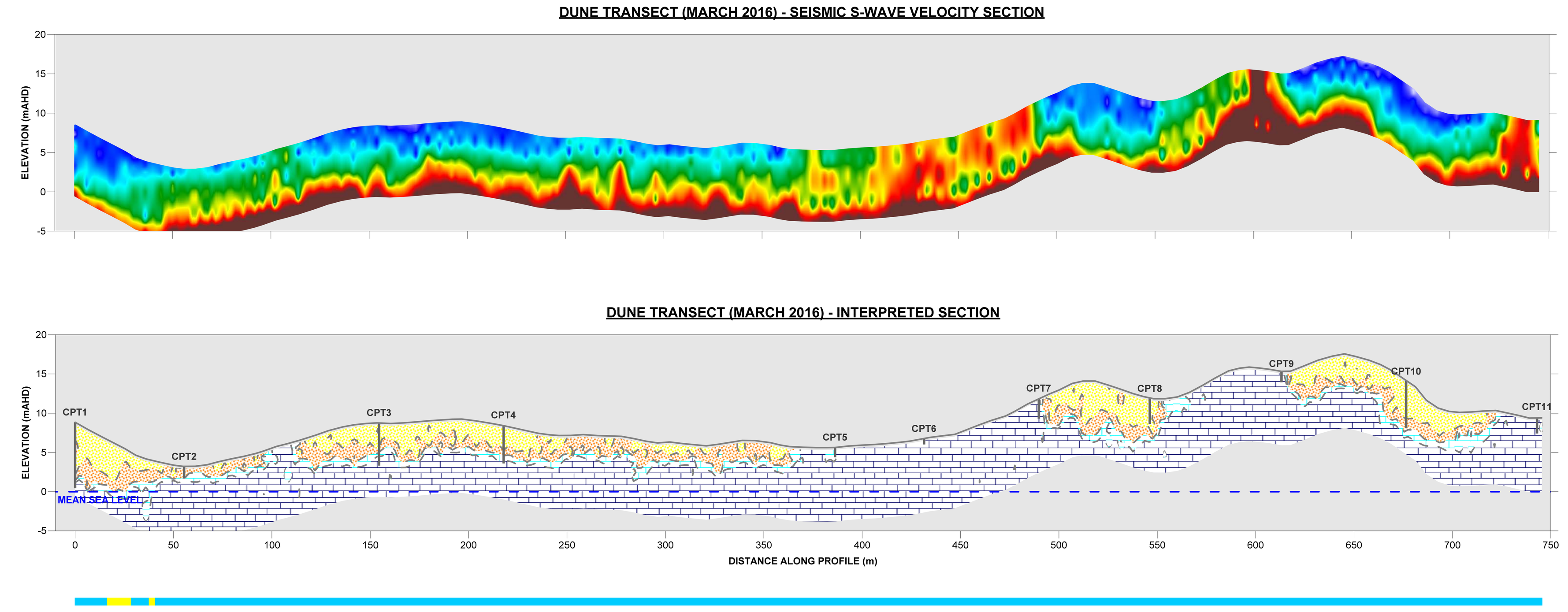
DUNE TIE IN (MAY 2014) - SEISMIC S-WAVE VELOCITY SECTION

DUNE TIE IN (MAY 2014) - INTERPRETED SECTION



DUNE TRANSECT (MARCH 2016) - SEISMIC S-WAVE VELOCITY SECTION

DUNE TRANSECT (MARCH 2016) - INTERPRETED SECTION



LEGEND - BASE MAP
- Geophysical Profile (May 2014) Southern Study Area
- Geophysical Profile (March 2016) Northern Study Area
- Geophysical Profile (August 2016) Infill Study Area
- CPT Point (May 2014) Southern Study Area
- CPT Point (March 2016) Northern Study Area
- CPT Point (August 2016) Infill Study Area

LEGEND - INTERPRETED SECTION
- Mean sea level within interpreted moderate strength limestone
- Mean sea level within interpreted low to moderate strength limestone
- Mean sea level within interpreted sand
- Sand - low compaction: S-wave velocity < 275m/s, P-wave velocity < 550m/s
- Sand - moderate compaction: S-wave velocity 275-350m/s, P-wave velocity 550-800m/s
- Limestone - low to moderate rock strength: S-wave velocity 350-400m/s, P-wave velocity 800-1000m/s
- Limestone - moderate rock strength: S-wave velocity > 400m/s, P-wave velocity > 1000m/s

LEGEND - VELOCITY SECTION

Seismic S-wave Velocity (m/s): 150 200 250 300 350 400 450 500 550 600 650 700 750

Seismic P-wave Velocity (m/s): 250 500 750 1000 1250 1500 1750 2000

Vertical metres: 0 12.5 25 37.5 50
Horizontal metres: 0 50 100 150 200

N

NOTES
Coordinates are in GDA94, MGA Zone 50.
Aerial image from Landgate February 2016
Drawing to be used in conjunction with report 70345, refer to report for investigation details, exclusions and limitations.

Date	15 August 2016	Paper Size	A0
Scale	1:2000 horizontal 1:500 vertical	Drawn	AHWS
Drawing	70345-05	Revision	A-1

CLIENT: DEPARTMENT OF TRANSPORT

TWO ROCKS VULNERABILITY STUDY, WESTERN AUSTRALIA
COMBINED INVESTIGATION RESULTS - SOUTHERN, NORTHERN AND INFILL

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