water affairs

Department:
Water Affairs
REPUBLIC OF SOUTH AFRICA

REPORT NO: P WMA 11/U10/00/3312/3/2/2

The uMkhomazi Water Project Phase 1: Module 1: Technical Feasibility Study: Raw Water

GEOTECHNICAL REPORT

SUPPORTING DOCUMENT 2:

SEISMIC REFRACTION INVESTIGATION AT THE PROPOSED UMKHOMAZI WATER PROJECT PHASE 1

FINAL

OCTOBER 2014

W86_2013/J01763

Project name:	***The uMkhomazi Water Project Phase 1: Module 1: Technical Feasibility Study Raw Water***
Report title:	***Geotechnical report***
Sub-report title:	***Supporting document 2: Seismic Refraction Investigation at the Proposed uMkhomazi Water Project Phase 1***
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PSP project reference no.:	***J01763***
DWA Report no.:	***P WMA 11/U10/00/3312/3/2/2***
Status of report:	***Final***
First issue:	***March 2013***
Final issue:	***October 2014***

CONSULTANTS: AECOM (BKS*) in association with AGES, MM&A and Urban-Econ.

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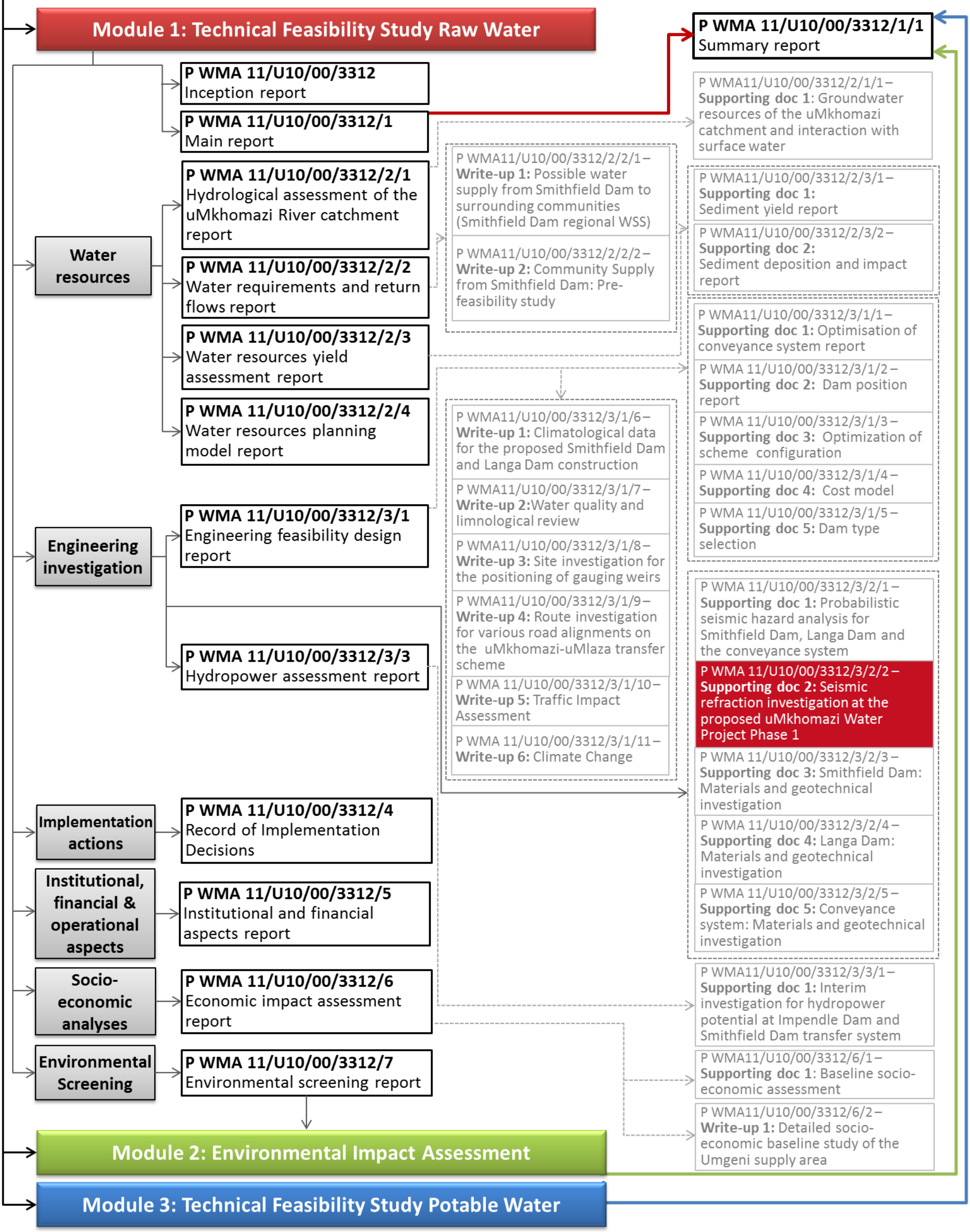
PREAMBLE

In June 2014, two years after the commencement of the uMkhomazi Water Project Phase 1 Feasibility Study, a new Department of Water and Sanitation was formed by Cabinet, including the formerly known Department of Water Affairs.

In order to maintain consistent reporting, all reports emanating from Module 1 of the study will be published under the Department of Water Affairs name.

The uMkhomazi Water Project Phase 1

LIST OF REPORTS



DISCLAIMER

It should be noted that non-invasive geophysical investigations and the interpretation of data from these investigations are inherently ambiguous. Anomalies and anomalous variations cannot be accurately and unambiguously traced to their source and origin, and various assumptions have to be made in terms of the interpretation of these data sets. Different sources of geophysical anomalies may be represented as very similar anomalies in the results, making the true interpretation of these features difficult, ambiguous and prone to error.

It should thus be noted that due to the nature of geophysical investigations and the non-uniqueness of geophysical interpretations, OPEN GROUND RESOURCES cannot be held responsible for any damages that may arise from correct or incorrect interpretation of geophysical results by OPEN GROUND RESOURCES or any other party.

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LIST OF ABBREVIATIONS

SR	Seismic Refraction
TT	Travel Time
HWF	Highly Weathered and Fractured Bedrock
MWF	Mediumly Weathered and Fractured Bedrock
SWF	Slightly Weathered and Fractured Bedrock

1 INTRODUCTION

Open Ground Resources was contracted by Geomech Africa (Pty) Ltd to conduct a Seismic Refraction investigation as part of the geotechnical investigation for the uMkhomazi Water Project Phase 1, Project Number W-0259-WTE/1.

The following sites were identified for the Seismic Refraction investigation:

- Smithfield Dam Site
- Tunnel Inlet Portal
- New Mbangweni Dam Site (*see note below)
- Tunnel Outlet Portal Site

The Smithfield Dam site and the Tunnel Inlet Portal sites are located approximately 60km WSW of Pietermaritzburg in Kwazulu-Natal. The proposed New Mbangweni site and the Tunnel Outlet Portal are located approximately 20 km from Pietermaritzburg on the Baynesfield Estate. A total linear distance of 6,278 metres was specified in the requirements for the survey.

Detailed specifications for the Seismic survey were provided in the tender document "*Invitation for Quotation Seismic Refraction Survey under BKS Contract W-0259-WTE/1*" dated 31 October 2012.

The fieldwork was conducted in December 2012 and January 2013.

NOTE:

The "New Mbangweni Dam Site" was the initial proposed site for the balancing dam. This option was subsequently discarded in favour of the Langa Dam site also on the Mbangweni River.

2 GEOLOGY

The geology of the area is comprised of the Beaufort and Ecca groups consisting of typically shales, sandstones, mudstones, coal and dolerite intrusions in the form of dykes and/or sills.

3 DATA ACQUISITION & PROCESSING

3.1 INSTRUMENTATION

Instrument:	Geode 24 channel seismograph, Trimble RTK R8 GNSS GPS
Geophones:	24
Source:	8.3 kg Hammer and Plate Energy Source
Geophone spacing:	5 metres
Number of shots:	7 – 9 shots per spread
Number of stacking:	24 - 120
Filters:	No filters applied during data acquisition

3.2 DESCRIPTION OF SR TRAVERSES

A total of 18 traverses were acquired as listed in **Table 3.1**.

Table 3.1: List of seismic refraction (SR) traverses

Name	Length (m)	Comments
Line Q1Q2	595	Smithfield Dam Quarry
Line Q3Q4	715	Smithfield Dam Quarry
Line Q5Q6	355	Smithfield Dam Quarry
Line A1A2	595	Smithfield Dam
Line E1E2	595	Smithfield Dam
Line L1L2	415	Smithfield Dam
Line S1S2	595	Smithfield Dam
Line R1R2	785	Smithfield Dam
Line T3T4	235	Smithfield Dam
Line T1T2	335	Smithfield Dam
Line I1I2	355	Inlet Portal
Line N1N2	160	New Mbangweni Dam
Line N1AN2A	115	New Mbangweni Dam
Line G1G2	115	New Mbangweni Dam
Line G2AG3A	115	New Mbangweni Dam
Line G3BG4	235	New Mbangweni Dam
Line O1O2	475	Outlet Portal
Line O3O4	235	Outlet Portal
	7,025	**TOTAL LINEAR DISTANCE (in metres)**

3.3 DESCRIPTION OF SEISMIC REFRACTION TECHNIQUE

The Seismic Refraction method utilizes seismic waves traveling through different parts of the subsurface. A seismic source is used to generate compressional waves, which is measured by a seismograph and a series of evenly spaced sensors (typically 12, 24, 48 or more geophones). Typical sources include a hammer and plate (for imaging depths of up to tens of metres), as well as explosives such as dynamite for deeper penetration. Seismic refraction is a quantitative method as the deliverables of the technique are p-wave velocities and depths of the various velocity layers. The technique is conventionally used to map bedrock topography as seismic velocity is an effective indicator of depth to bedrock as well as bedrock quality.

3.4 SURVEYING AND REFERENCING

A sub-metre accuracy Trimble RTK R8 GNSS GPS system was used to survey geophone and shot positions, and to derive topographical variations. Survey data was recorded in the WG-31 coordinate system for the New Mbangweni Dam and Transfer Tunnel sites. The Smithfield Dam and Inlet Portal sites were acquired in the WG-29 system although the results and coordinates are presented in WG-31 to comply with the DXF maps provided by the Client.

3.5 PROCESSING

Currently two processing methodologies are typically applied when seismic refraction data is processed of which one provides a discreet layered model and the other a continuous velocity model (tomography velocity processing). The discreet layered model assumes that the earth consists of discreet velocity layers (each with a fixed velocity) where the tomography option allows the velocity to vary continuously (basically dividing the earth into numerous velocity layers).

The tomography model is more acceptable in areas where the weathering profile changes gradually with depth compared to other refraction interpretation models where a 2 or 3-layer model with discreet velocities are used. It also provides more realistic subsurface velocities when lateral velocity variations are present such as in the cases of faults/fracture zones and also where significant topographical variations are present.

The gradient of velocity change with depth is an indication of the ‘sharpness’ of the transition zone. As a rule of thumb, the software resolves structures with dimensions about half the receiver spacing, but this can vary depending on the presence or absence of strong lateral and vertical velocity variations. SeisImager 2D, unlike traditional refraction software, thus images velocity gradients in the subsurface.

The method will introduce a gradient between horizons defined by discrete velocities. ***The interface between layers is the depth at which the gradient change is the steepest.*** In general, this will be shallower than the actual depth at which the layer velocity is encountered which should be taken into account when comparing the results with methods that produce discreet layer models.

For example, the interface between layers that have discreet velocities of 500 m/s and 2,000 m/s, will not be at 2,000 m/s, but rather shallower where velocities are about

1,250-1,500 m/s. As often the case in reality SeisImager 2D reveals subsurface velocities as gradients and not solid interfaces.

4 MEASURING TECHNIQUES AND METHODOLOGY

4.1 SEISMIC VELOCITIES

In the case of seismic refraction the **Table 4.1** describes a general relationship between soil and rock properties and compressional seismic velocity:

Table 4.1: Generalized P-wave seismic velocities

#	Description	Seismic velocity
1	Overburden consisting of transported material & completely weathered rock	0 – 1000 m/s
2	Highly weathered/fractured to moderately weathered/fractured rock	1000 – 2000 m/s
3	Moderately to slightly weathered/fractured rock	2000 – 3000 m/s
4	Slightly weathered/fractured to unweathered/ fractured rock	> 3000 m/s

Note that **Table 4.1** is a generalized table, and variations do exist for different rock types, especially between sedimentary and igneous rocks. The seismic refraction technique measures either compressional (p-wave) or shear (s-wave) wave velocities with compressional p-wave velocities measured in this investigation. Compressional wave velocity of a material depends on the density as well as the elastic moduli, and can in general be used to classify relative density and rock strength. However, in general, it is not possible to accurately distinguish between highly weathered rock and highly fractured rock, or between slightly weathered rock and slightly fractured rock. The degree of water saturation also increases the compressional wave velocity of material.

4.2 BOREHOLE INFORMATION

None available at time of this report.

4.3 TOMOGRAPHY PROCESSING METHODOLOGY

The Seismic Tomography method was used to process and present the SR results. This method is more useful in areas of significant topographical variations and where possibly large lateral variations in seismic velocity are present. The observed travel time curves for the seismic results also suggested that the tomographical approach would be preferred due to the difficulties in extracting a simple 2 or 3 layer seismic layered model from the SR results.

The tomography method produces a continuous seismic velocity model and not discreet velocity boundaries as with methods such as the delay time, etc. the interpretation of the results is basically based on the following two parameters:

- The presence of a high velocity gradient which one will except when a sharp seismic velocity boundary is present such as between overburden and bedrock without any gradual increase in velocity.
- The actual seismic velocity present at specific depths.

One would typically look for both of the above in the interpretation of depth to bedrock. In this study the contour lines representing seismic velocity of 2,000 m/s and 4,000 m/s have been highlighted on the results as these velocities typically represent highly weathered bedrock and fresh bedrock. High velocity gradients are also of interest as these represent the transition between different velocity zones such as between overburden and weathered bedrock, and then also between weathered and fresh bedrock.

5 SMITHFIELD DAM SEISMIC RESULTS

5.1 LINES A1A2 AND E1E2 (FIGURES 9 & 10)

These lines are located on the eastern side of the area shown in **Figure 1** in **Appendix B**. The southern part of the area is dominated by a dolerite hill and the end of A1A2 stops just at the foot of the dolerite hill. The results are displayed in **Figures 9** and **10** (**Appendix B**).

Line A1A2 is characterized by the presence of relatively shallow high velocities (> 2,000 m/s at depths < 5 metres) and slightly deeper in some areas. A deeper refractor can be observed at a depth of approximately 30 metres at the start of the line which becomes shallower towards 350-500 m chainage. This refractor represents seismic velocities > 4,500 m/s and suggests a bedrock layer which is relatively unweathered and slightly fractured. The shallow presence of the 2,000 m/s velocity layer suggests that weathered bedrock is relatively close to surface and that fresh bedrock is also present at shallower depths between 350 and 500 metres chainage. The 4,000 m/s boundary is present at a depth of approximately 20 metres from 0 to 250 metres and then becomes shallower to approximately 10 metres depth; this velocity can be used as a good indicator of relatively good bedrock.

Line E1E2 shows a more homogeneous velocity model compared to A1A2 and with a shallow 2,000 m/s velocity boundary less than 5 metres depth which are interpreted as shallow weathered rock. Fresh bedrock appears to be slightly shallower between 300 and 400 m chainage as indicated.

Line E1E2 similar to A1A1 shows weathered rock velocities (2,000 m/s) at shallow depth (< 5 m depth) which is very consistent along the line as indicated on **Figure 10** (**Appendix B**). Approximate depth to fresh, unweathered and unfractured bedrock is also indicated, this interface may have an error of +-5m and should be calibrated after correlation with drilling results.

The 3,000 m/s velocity boundary is present at a depth of 10-15 metres on average and should be a good indicator of the depth to competent bedrock.

5.2 QUARRY LINES (FIGURES 11, 12 & 13)

A total of three lines (Q1Q2, Q3Q4, and Q5Q6) were conducted on the potential dolerite quarry site east of the river.

Line Q1Q2 (**Figure 11** in **Appendix B**) shows a smooth increase in seismic velocity with depth without a distinct velocity boundary, suggesting that the bedrock has a weathering profile with smooth decrease in weathering with depth. The 2,000 m/s contour line appears to be associated with a slight velocity gradient and this line is interpreted as the depth to weathered rock which occurs at an average depth of approximately 10 metres. SWF bedrock appears to be present at a depth of approximately 20 metres, and possibly shallower at the start of the line (0 to 200 m chainage).

Line Q1Q2 and Q5Q6 show a distinct high velocity anomaly at respective chainages of 140 and 125 metres which might suggest a vertical structure although this may also relate to a processing artefact.

Depth to fresh bedrock (4,000 m/s) appears to relatively shallow on Q1Q2 (< 5 to 10 metres) and increase in depth on Q3Q4 which may be expected as Q3Q4 is located at a higher elevation. This is also clearly evident on Q5Q6 with shallower bedrock at the beginning and end of the traverse and with a zone between 150 and 300 metres chainage where weathering appears to be deeper.

5.3 LINES T1T2, T3T4 AND R1R2 (FIGURES 14, 15 & 16)

A total of three traverses were acquired on the right flank of the river of which R1R2 was the longest traverse. The seismic results for R1R2 presented in **Figure 16** (**Appendix B**) shows the presence of the 2,000 m/s velocity contour at an average depth of approximately 20-30 metres although much shallower at the beginning of the traverse. This interface is indicated as the top of the weathered bedrock with fresh bedrock (4,000 m/s) interpreted at 10-15 metres below this interface generally along the traverse as indicated in **Figure 16** (**Appendix B**). The shorter traverses show similar results compared to R1R2 suggesting a relatively horizontal bedrock depth and weathering profile.

5.4 SPILLWAY LINES S AND L (FIGURES 17 AND 18)

Line S1S2 is located with the end of the traverse at the edge of the river with results displayed in **Figure 17** (**Appendix B**). Bedrock appears to be shallow at the edge of the river as anticipated (end of traverse) and also relatively deeper (> 20 metres) at the start of the line. A prominent ridge with shallower high velocity zone can be observed between 250 and 350 m chainage.

Line L1L2 shows very shallow bedrock at the start of the traverse at the edge of the river @ -60 m chainage. Depth to HWF bedrock generally increases to approximately 20 metres at the end of the line.

6 TRANSFER TUNNEL INLET PORTAL SEISMIC RESULTS

6.1 LINE I1-I2 (FIGURE 19)

The seismic results for Line I1I2 suggest weathered rock close to the surface (~5 metres depth) as indicated by the 2,000 m/s velocity boundary. Less weathered and fractured rock appears to be at 15-20 metres below surface although shallower between 150 and 300 metres chainage.

7 New Mbangweni Dam and Outlet Portal Seismic Results

NOTE:

*The coordinates of the New Mbangweni Dam site are **29°46'30.38''S, 30°17'54.51''E**. The Langa Balancing Dam site, the location that was ultimately selected for the balancing dam, is approximately 1.5 km south of this area. Additional seismic refraction investigation at this site may be considered.*

7.1 Lines N1N2 and N1AN2A (Figure 20)

The proposed line N1N2 had to be split into two sections due to inaccessible wet conditions (refer to **Figure 7** in **Appendix B**). The seismic results clearly show very shallow weathered bedrock at the end and start of the respective lines in the marshy area between the two lines. Weathered bedrock then increase to depths of between 20 and 30 metres towards the start of N1N2 and the end of N1AN2A.

7.2 Lines G1G2, G2AG3A, G3BG4 (Figures 21 to 23)

A total of three lines were further conducted south of lines N1N2 and N1AN2A as shown in **Figure 8** (**Appendix B**). Results for G1G2 shows weathered bedrock at a depth of less than 10 metres, becoming shallower towards the end of the traverse.

The results for G2AG3A shows shallow (<5 metres depth) weathered rock for the first 50 metres and it appears to increase in depth to about 20-25 metres at a chainage of approximately 80 metres. Fresh bedrock (>4,000 m/s) is interpreted at a depth of less than 10 metres for the first 50 metres.

Traverse G3BG4 appears to be much more deeply weathered with HWF bedrock at a depth of 10 metres at the start and then increasing to 20-25 metres towards the end of the traverse.

7.3 LINES O1O2 AND O3O4 (FIGURES 24 & 25)

These two traverses are separated by a large gap due to inaccessibility as a result of sugar cane plantations. Results for O1O2 shows shallow weathered bedrock at the start and a ridge of shallow weathered rock towards the end of the line. Depth to HWF bedrock appears to be between 20 and 25 metres depth from 100 to 400 m chainage.

Line O3O4 shows very low velocities (< 500m/s) for the first 10 metres depth, suggesting unconsolidated material, possibly transported. Bedrock appears to be very well defined with an average depth of approximately 30 metres to HWF bedrock. Fresh bedrock appears at a depth of 35 metres for the first 150 metres, and then possibly increases slightly with depth towards the end of the line.

8 CONCLUSIONS AND RECOMMENDATIONS

A total linear distance of 7,025 metres was acquired using the Seismic Refraction technique at the Smithfield Dam, Transfer Tunnels and New Mbangweni Dam sites. The data quality is on average of a high quality and the seismic tomographical velocity models derived are considered to be accurate velocity models of the subsurface conditions.

A tomographical interpretation technique was used and smooth models of continuously varying seismic velocity were derived during the processing of the data. These models depict seismic velocity changes as changes in seismic velocity and not as very sharp boundaries as with layered model processing.

Interpretation of the results relied on the measured seismic velocities as well as the seismic velocity gradient as both are indicative of the presence of highly weathered material and overburden and bedrock in varying degree of weathering and/or fracturing. The 2,000 and 4,000 m/s velocity boundaries were indicated on each velocity section to highlight the approximate depth level of highly weathered and fractured bedrock and relatively fresh bedrock, although these are simply approximations based on typical seismic velocities.

Some interesting anomalies of relatively shallow and deeper bedrock were observed which should be investigated by drilling. A final interpretation of depth to bedrock and the significance of other geological units can be done when borehole results are available for correlation with the seismic refraction results.

Yours sincerely,

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9 REFERENCES

Milsom, J. (2003). *Field Geophysics, The Geological Field Guide Series.* West Sussex: John Wiley & Sons Ltd.

Appendix A

List of seismic pegs

APPENDIX A: LIST OF SEISMIC PEGS

Line	X (WG-31)	Y (WG-31)	Peg
Q1Q2	-102226.86	-3295789.74	Q1Q2+00
	-102194.44	-3295698.16	Q1Q2+100
	-102156.15	-3295599.48	Q1Q2+200
	-102114.70	-3295509.75	Q1Q2+300
	-102066.23	-3295420.89	Q1Q2+400
	-102024.76	-3295332.16	Q1Q2+500
	-101988.15	-3295251.51	Q1Q2+595
Q3Q4	-102074.26	-3295823.10	Q3Q4+00
	-102044.84	-3295731.58	Q3Q4+100
	-102005.39	-3295641.88	Q3Q4+200
	-101958.92	-3295553.06	Q3Q4+300
	-101916.45	-3295464.30	Q3Q4+400
	-101875.05	-3295371.57	Q3Q4+500
	-101829.54	-3295284.77	Q3Q4+600
	-101785.15	-3295191.98	Q3Q4+700
Q5Q6	-102158.61	-3295457.50	Q5Q6+00
	-102062.05	-3295488.83	Q5Q6+100
	-101967.56	-3295516.20	Q5Q6+200
	-101872.21	-3295535.55	Q5Q6+300
	-101821.88	-3295553.68	Q5Q6+355
A1A2	-101373.96	-3295544.91	A1A2+00
	-101317.51	-3295627.95	A1A2+100
	-101258.08	-3295709.93	A1A2+200
	-101196.78	-3295783.88	A1A2+300
	-101141.23	-3295872.94	A1A2+400
	-101086.88	-3295950.01	A1A2+500
	-101044.50	-3296029.29	A1A2+595
E1E2	-101913.14	-3296116.36	E1E2+00
	-101828.07	-3296061.88	E1E2+100
	-101738.90	-3296013.32	E1E2+200
	-101653.74	-3295963.84	E1E2+300
	-101571.72	-3295906.41	E1E2+400
	-101483.57	-3295856.87	E1E2+500
	-101407.46	-3295804.54	E1E2+595
L1L2	-102497.03	-3295840.43	L1L2-60
	-102508.06	-3295896.64	L1L2+00
	-102525.39	-3295992.95	L1L2+100
	-102542.66	-3296093.27	L1L2+200
	-102560.92	-3296193.60	L1L2+300
	-102567.98	-3296247.74	L1L2+355

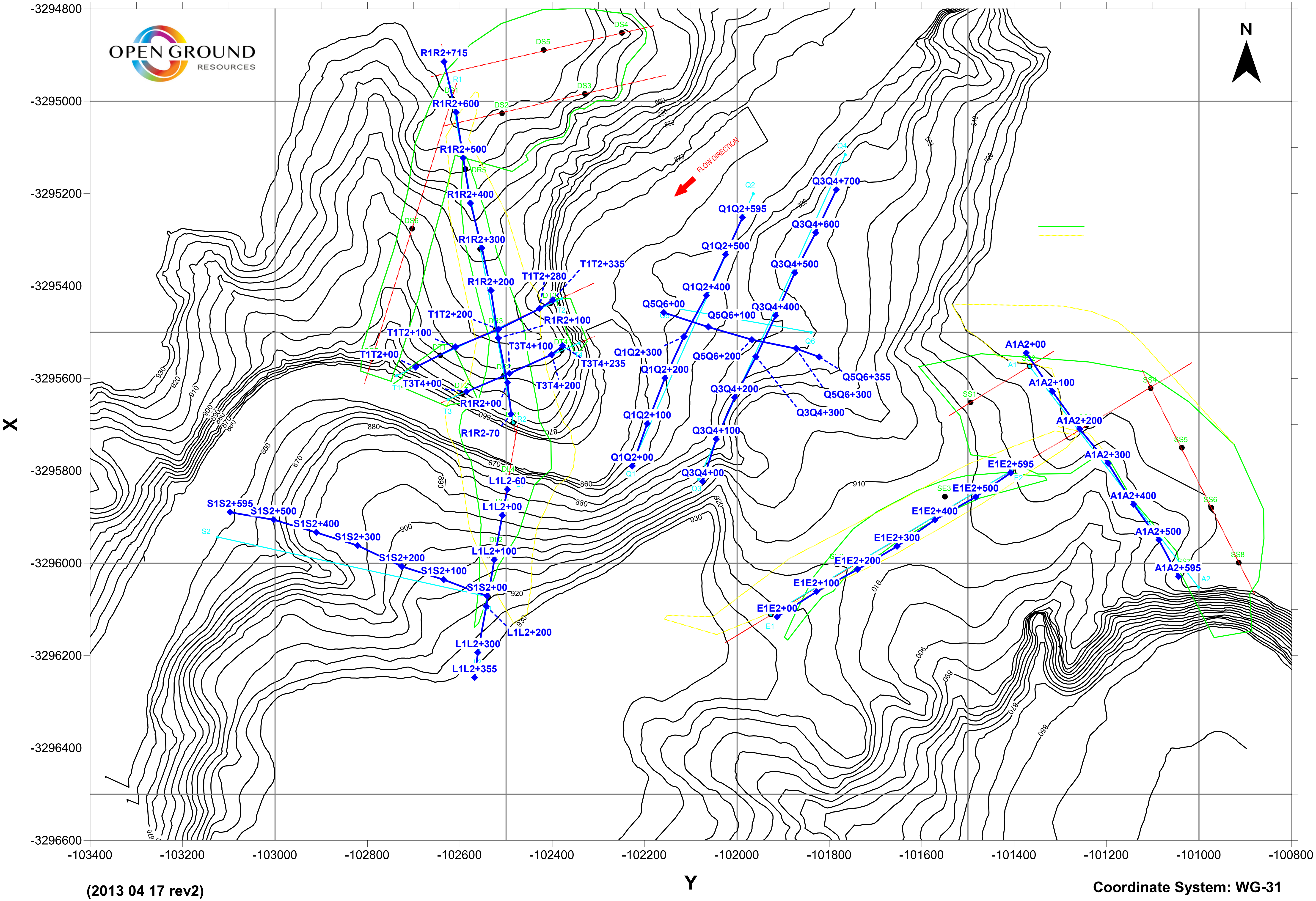
S1S2	-102541.04	-3296071.24	S1S2+00
	-102634.67	-3296035.86	S1S2+100
	-102725.18	-3296007.42	S1S2+200
	-102820.98	-3295962.07	S1S2+300
	-102910.49	-3295933.62	S1S2+400
	-103002.98	-3295906.22	S1S2+500
	-103097.28	-3295889.85	S1S2+595
R1R2	-102488.86	-3295677.26	R1R2-70
	-102497.04	-3295609.39	R1R2+00
	-102516.71	-3295512.72	R1R2+100
	-102532.50	-3295409.97	R1R2+200
	-102552.09	-3295318.30	R1R2+300
	-102576.79	-3295220.71	R1R2+400
	-102592.48	-3295122.96	R1R2+500
	-102608.20	-3295024.22	R1R2+600
	-102634.10	-3294914.65	R1R2+715
T3T4	-102585.71	-3295628.93	T3T4+00
	-102492.38	-3295589.31	T3T4+100
	-102401.07	-3295548.72	T3T4+200
	-102377.40	-3295529.31	T3T4+235
T1T2	-102695.65	-3295575.83	T1T2+00
	-102609.39	-3295532.33	T1T2+100
	-102516.04	-3295493.70	T1T2+200
	-102427.80	-3295449.16	T1T2+280
	-102399.12	-3295430.66	T1T2+335
I1I2	-101711.52	-3294419.57	I1I2+00
	-101606.38	-3294426.75	I1I2+100
	-101507.30	-3294430.03	I1I2+200
	-101409.21	-3294434.33	I1I2+300
	-101358.23	-3294432.45	I1I2+355
N1N2	-67460.54	-3295284.99	N1N2+00
	-67389.80	-3295346.46	N1N2+100
	-67341.48	-3295382.29	N1N2+160
N1AN2A	-67312.36	-3295499.09	N1AN2A+00
	-67218.32	-3295567.67	N1AN2A+115
G1G2	-67831.57	-3296852.69	G1G2+00
	-67724.64	-3296813.95	G1G2+115
G2AG3A	-67731.57	-3296805.41	G2AG3A+00
	-67671.45	-3296900.97	G2AG3A+115
G3BG4	-67691.72	-3296851.34	G3BG4+00
	-67602.77	-3296889.51	G3BG4+100

	-67514.34	-3296933.87	G3BG4+200
	-67486.03	-3296952.32	G3BG4+235
O1O2	-67409.37	-3295213.88	O1O2+00
	-67504.45	-3295214.64	O1O2+100
	-67599.90	-3295212.40	O1O2+200
	-67697.10	-3295208.94	O1O2+300
	-67791.89	-3295207.07	O1O2+400
	-67863.79	-3295199.41	O1O2+475
O3O4	-68294.38	-3295205.51	O3O4+05
	-68393.24	-3295201.90	O3O4+100
	-68492.61	-3295198.86	O3O4+200
	-68526.85	-3295196.87	O3O4+235

Appendix B

Figures

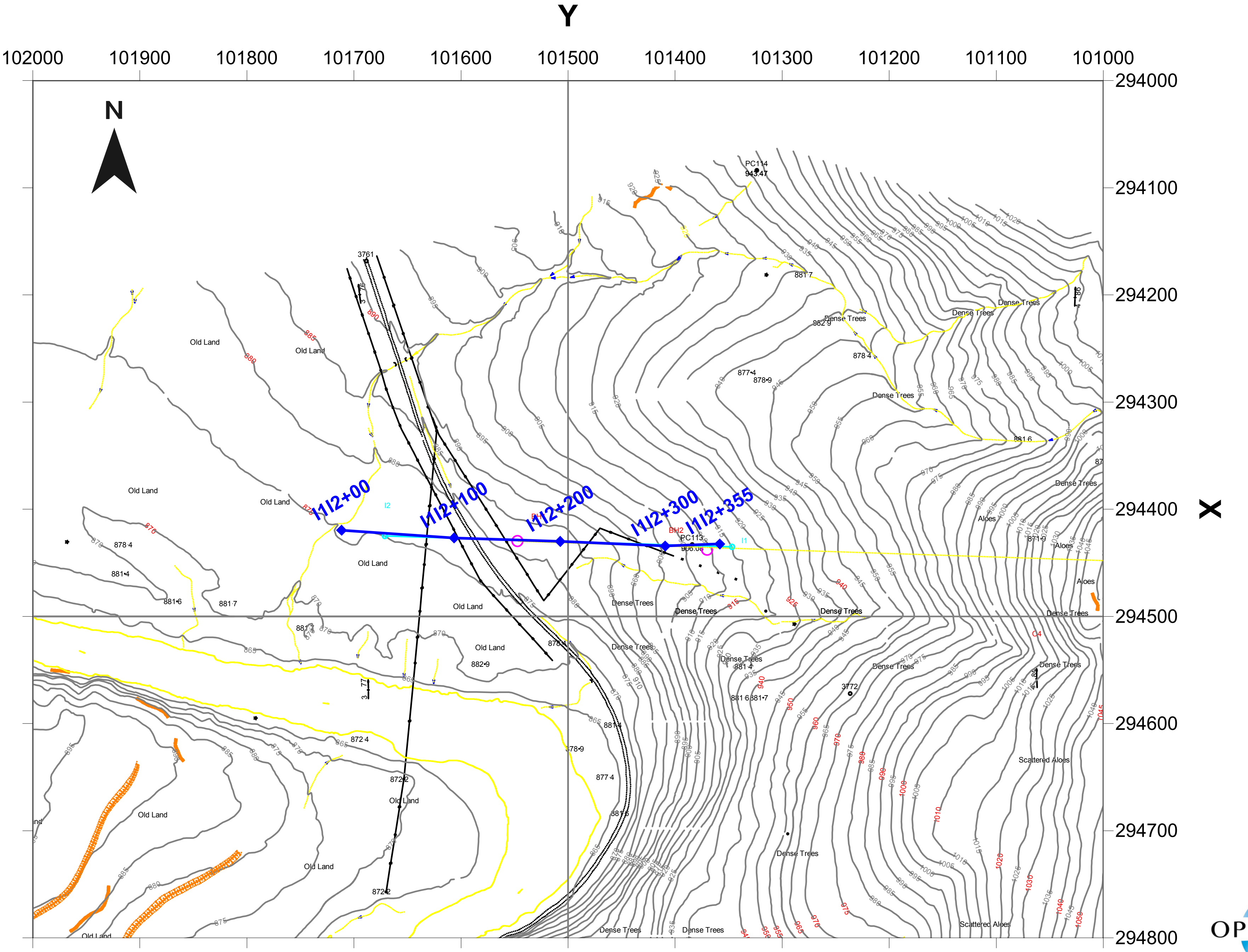
Figure 1. Smithfield Dam Locality Map of Seismic Refraction Traverses



(2013 04 17 rev2)

Coordinate System: WG-31

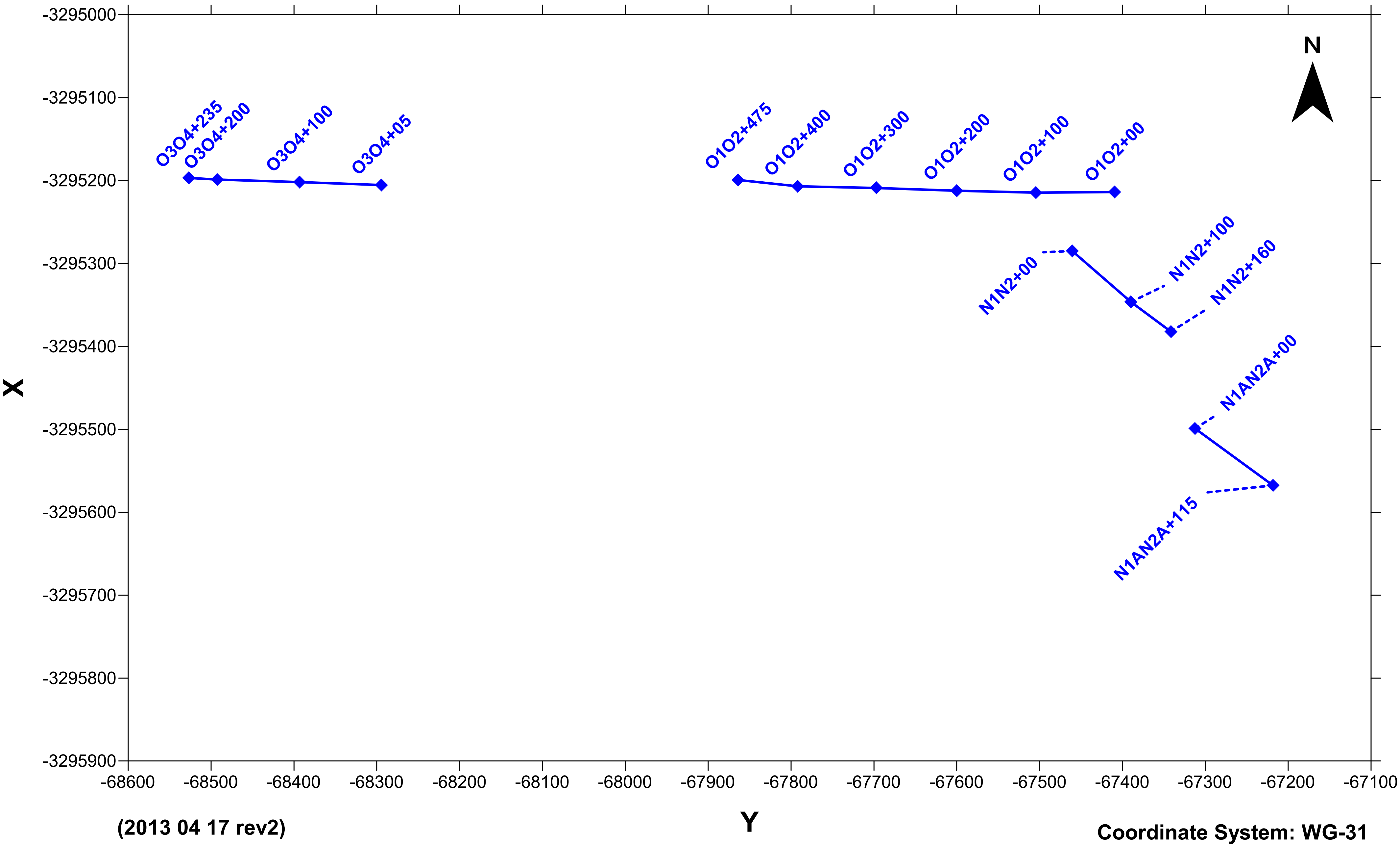
Figure 2. Transfer Tunnel Locality Map of Seismic Refraction Traverses



(2013 04 17 rev2)

Coordinate System: WG-31

Figure 3. New Mbangweni Dam Locality Map of Seismic Refraction Traverses (A)



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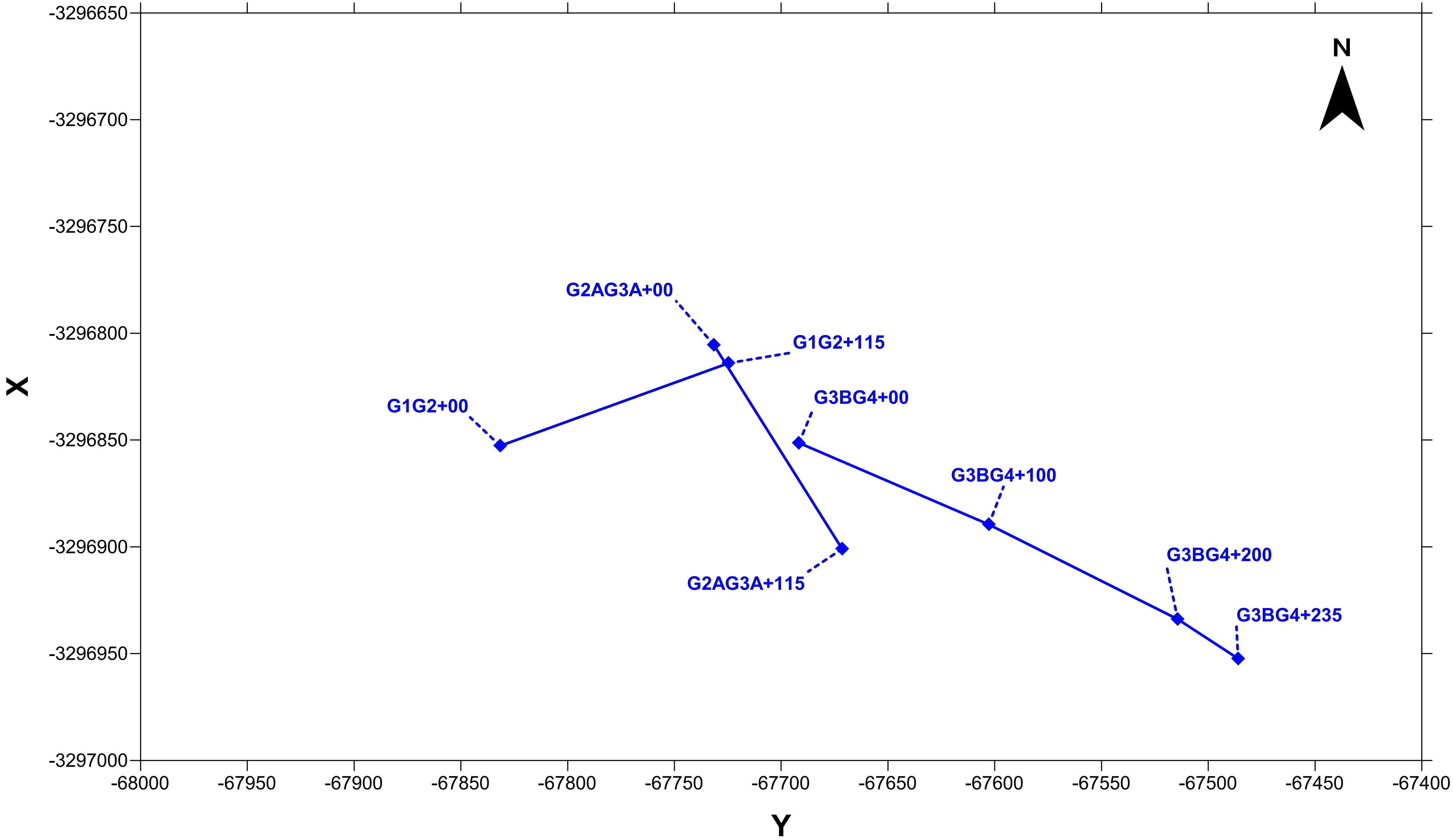
Coordinate System: WG-31

Figure 4. New Mbangweni Dam Locality Map of Seismic Refraction Traverses (B)



(2013 04 17 rev2)

Coordinate System: WG-31

Figure 5. Google Earth View of Smithfield Dam (not to scale)

Figure 6. Google Earth View of Transfer Tunnel (not to scale)

Figure 7. Google Earth View of New Mbangweni Dam (A)

Figure 8. Google Earth View of New Mbangweni Dam (B)

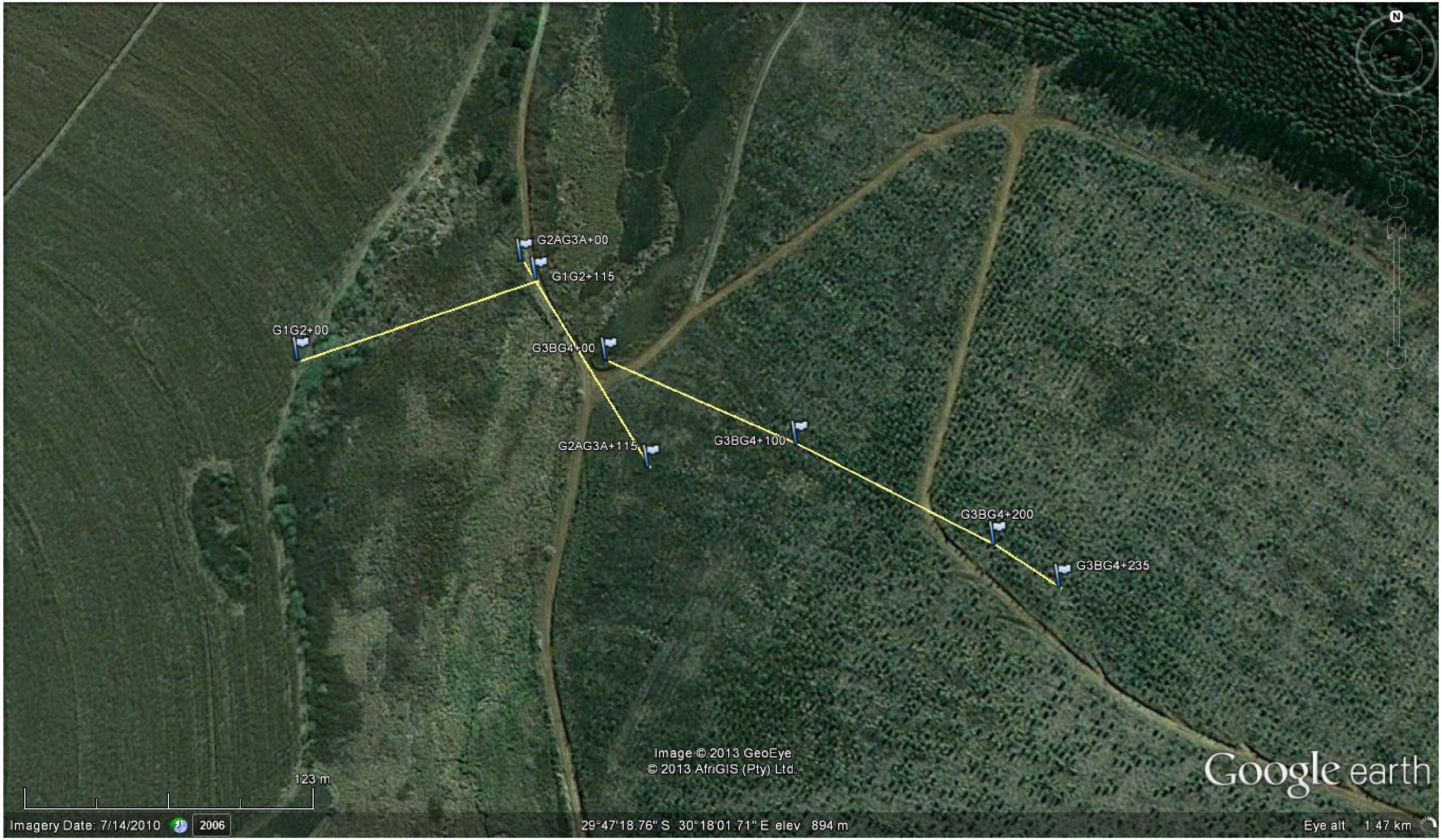


FIGURE 9: Traverse A1A2 Seismic Tomography Model (Smithfield Dam Site)

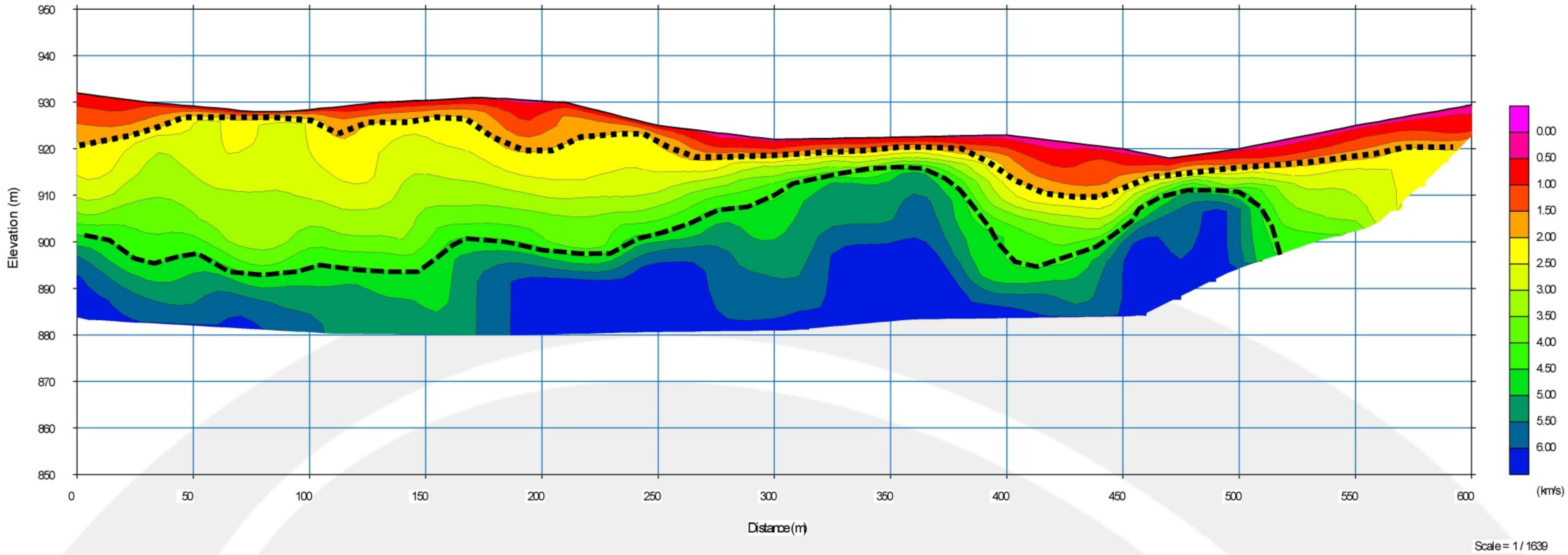


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FIGURE 10: Traverse E1E2 Seismic Tomography Model (Smithfield Dam Site)

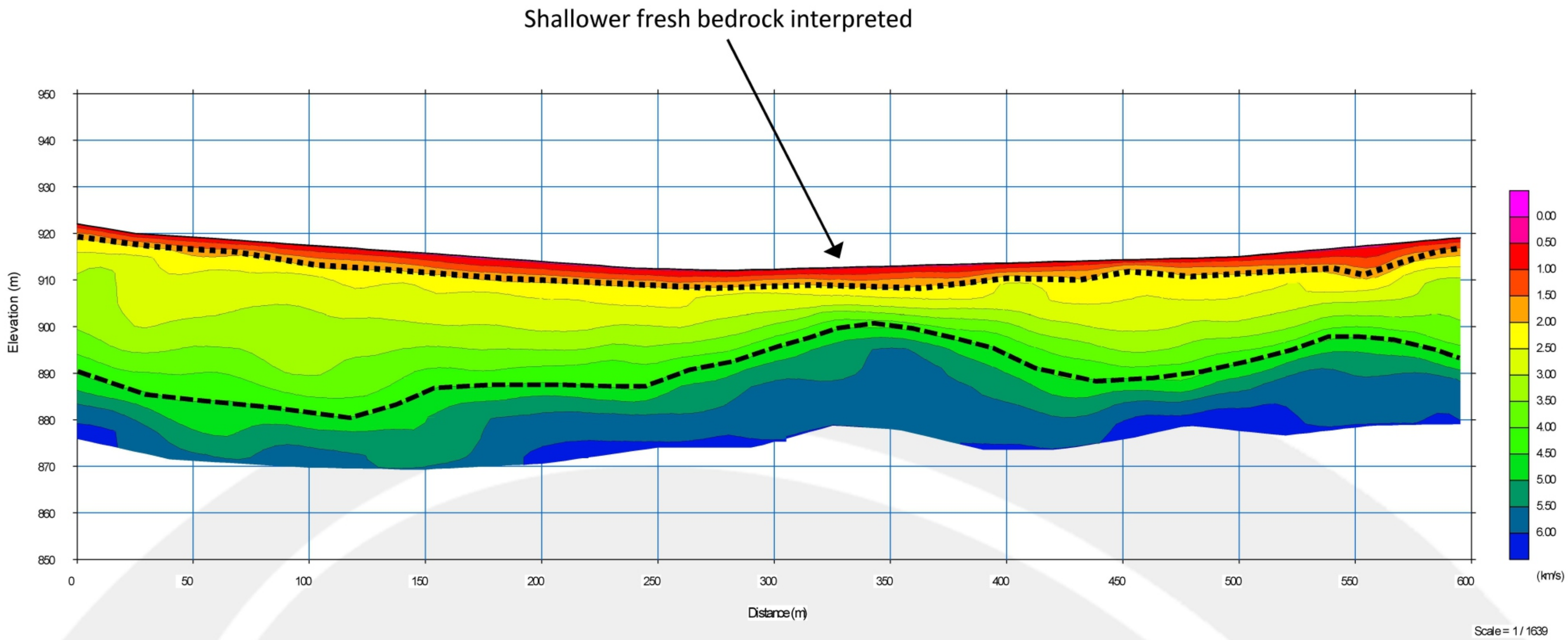

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FIGURE 11: Traverse Q1Q2 Seismic Tomography Model (Smithfield Dam Site)

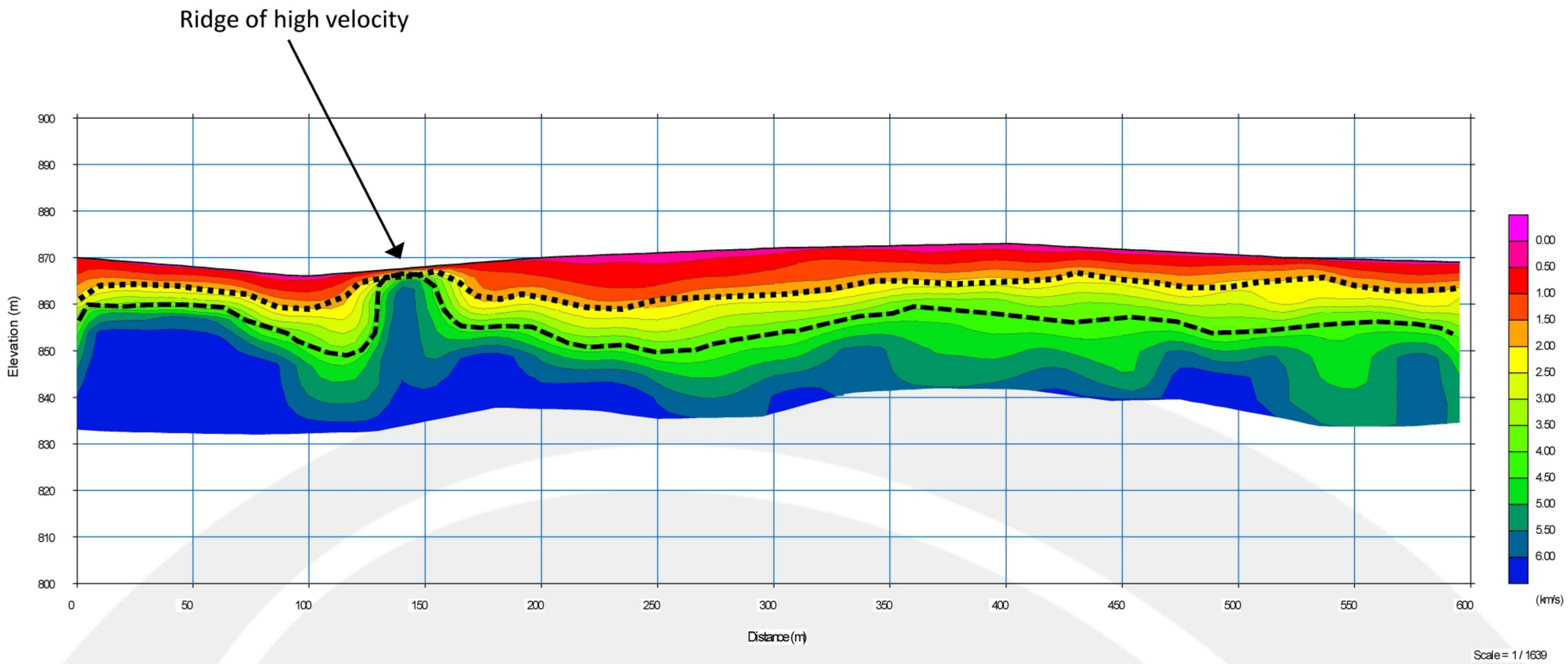

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FIGURE 12: Traverse Q3Q4 Seismic Tomography Model (Smithfield Dam)

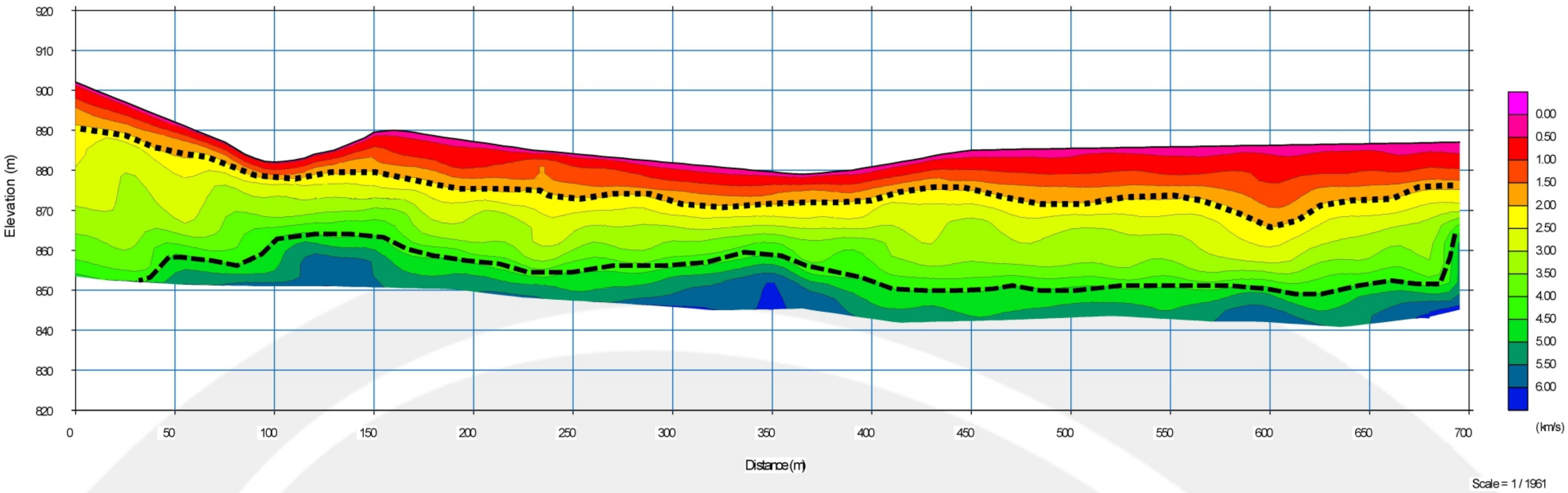

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FIGURE 13: Traverse Q5Q6 Seismic Tomography Model (Smithfield Dam)

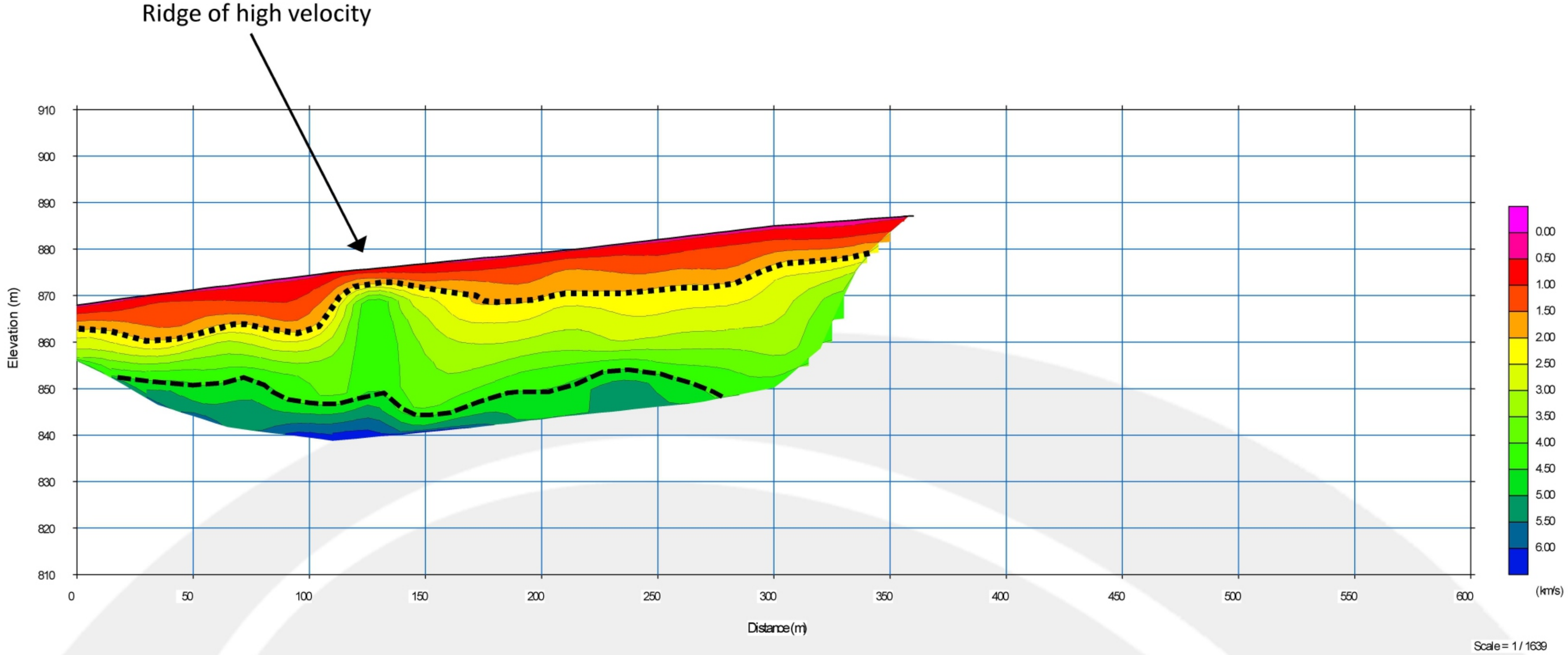

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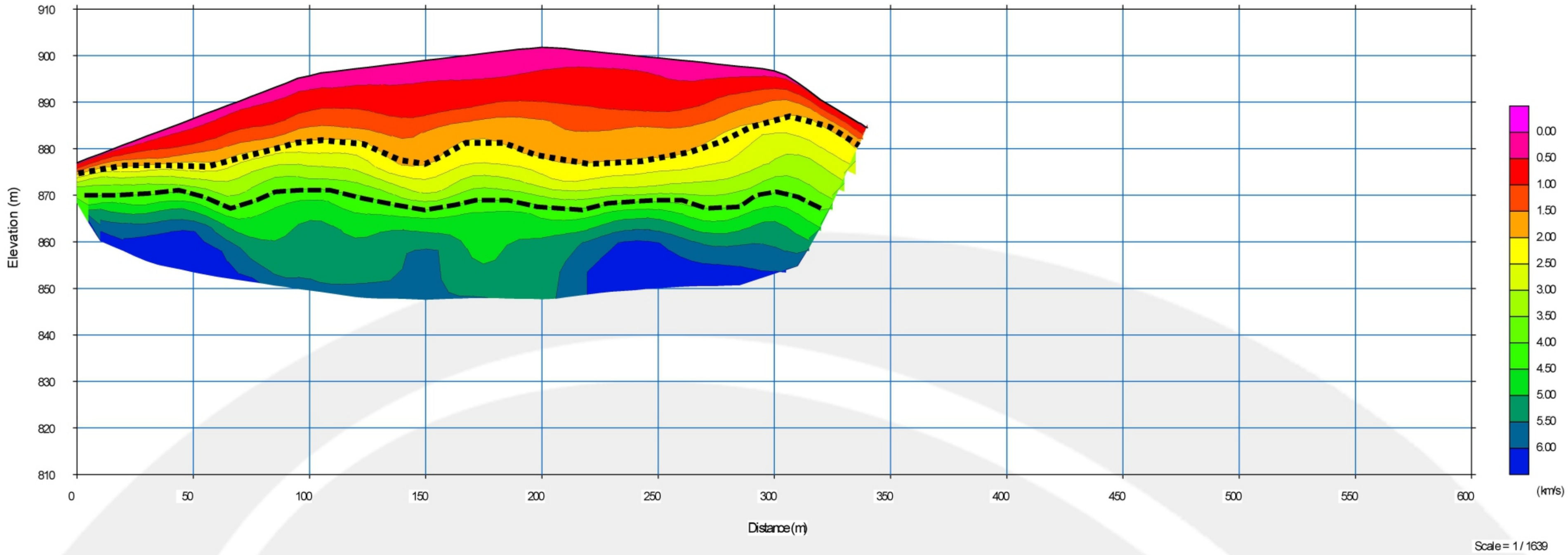
FIGURE 14: Traverse T1T2 Seismic Tomography Model (Smithfield Dam)



Relatively homogeneous velocity layers

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FIGURE 15: Traverse T3T4 Seismic Tomography Model (Smithfield Dam)

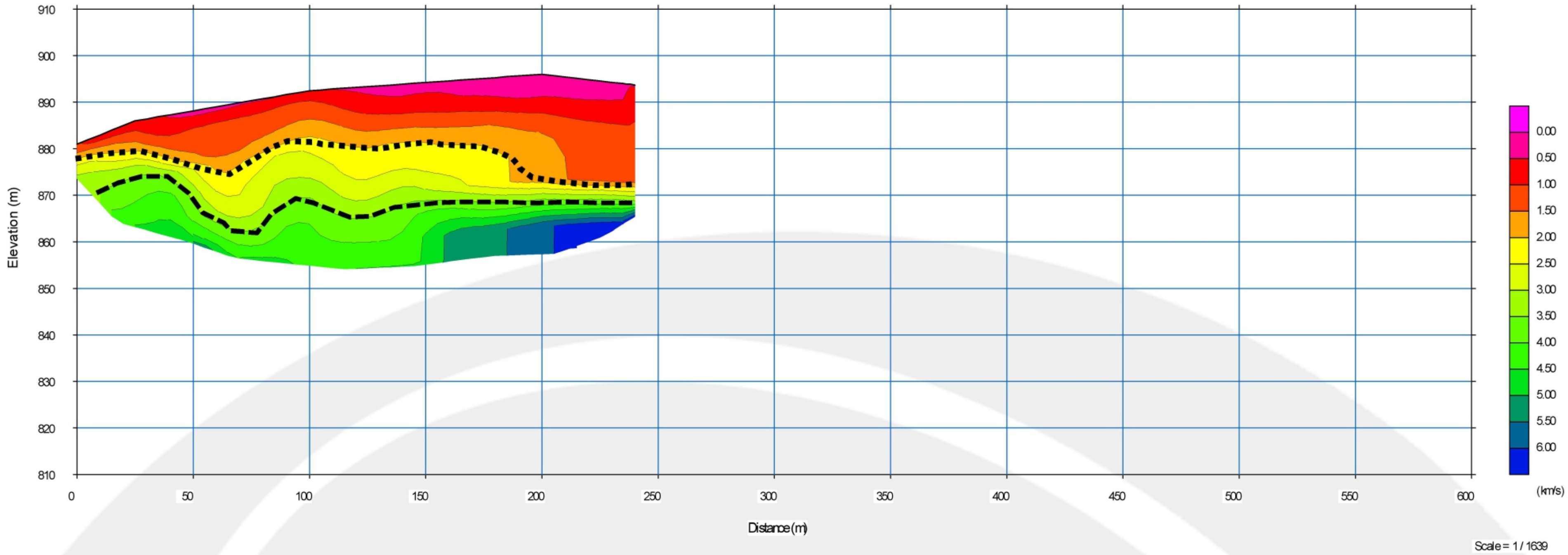

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FIGURE 16: Traverse R1T2 Seismic Tomography Model (Smithfield Dam)

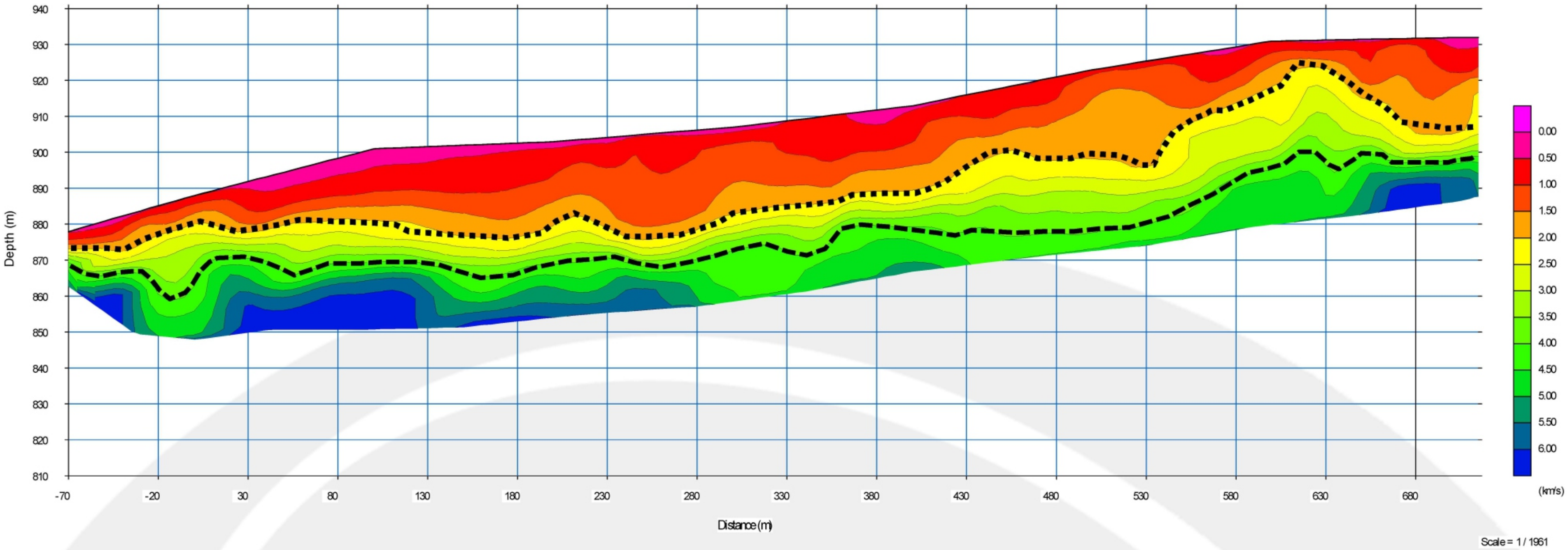

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FIGURE 17: Traverse S1S2 Seismic Tomography Model (Smithfield Dam)

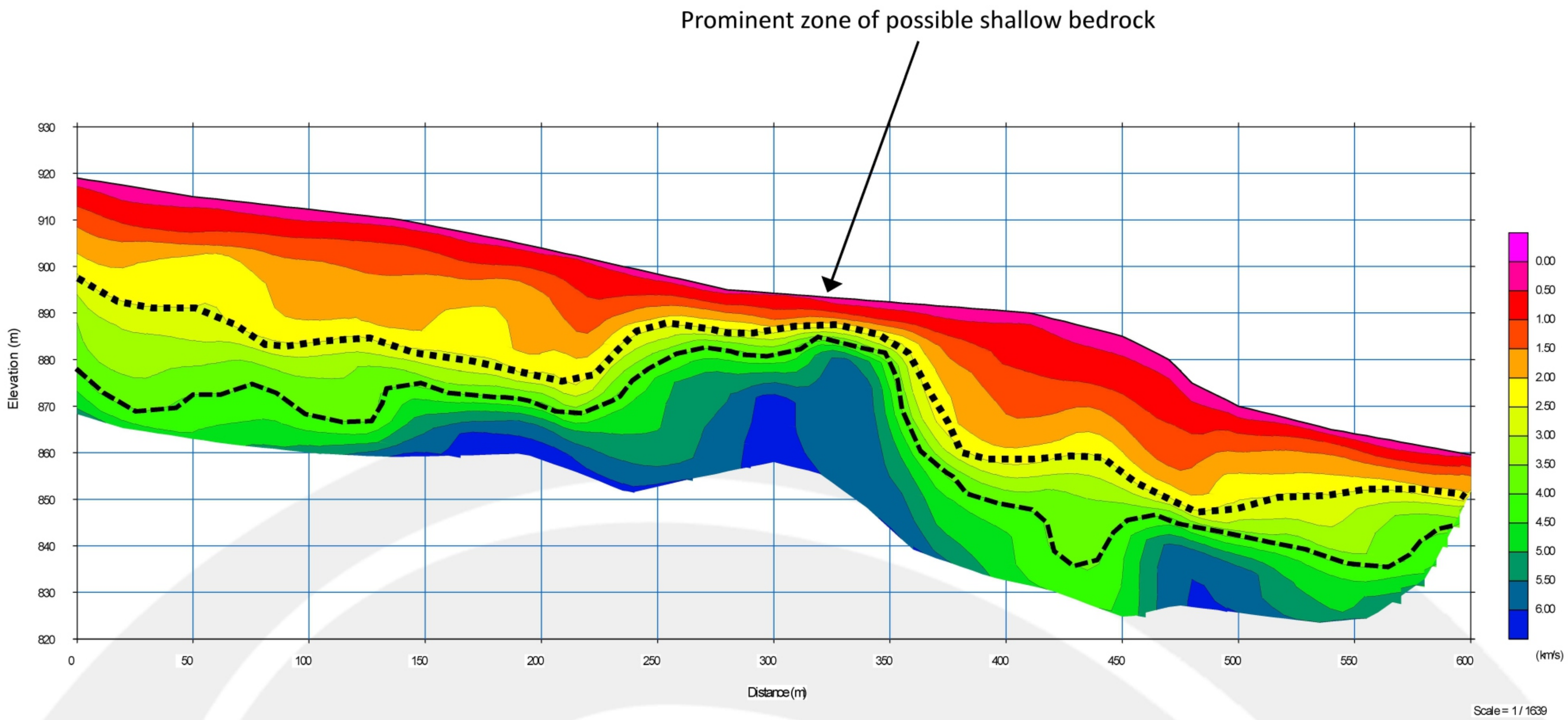

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FIGURE 18: Traverse L1L2 Seismic Tomography Model (Smithfield Dam)

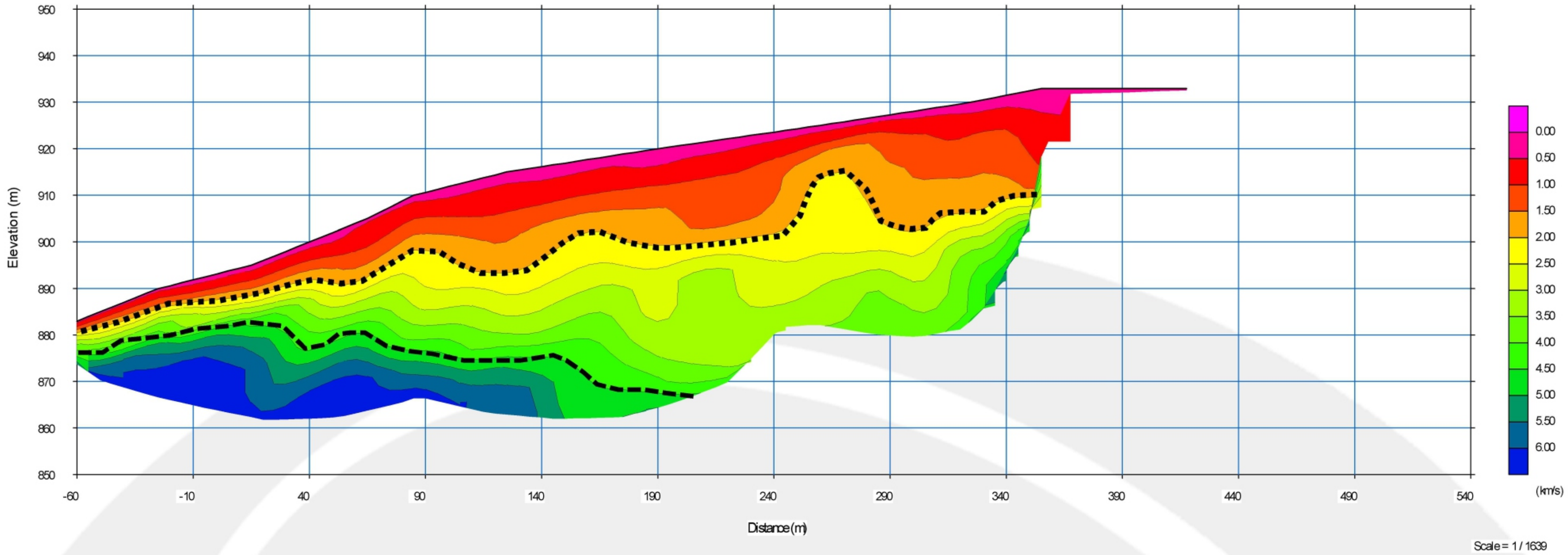

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FIGURE 19: Traverse I1I2 Seismic Tomography Model (Transfer Tunnel)

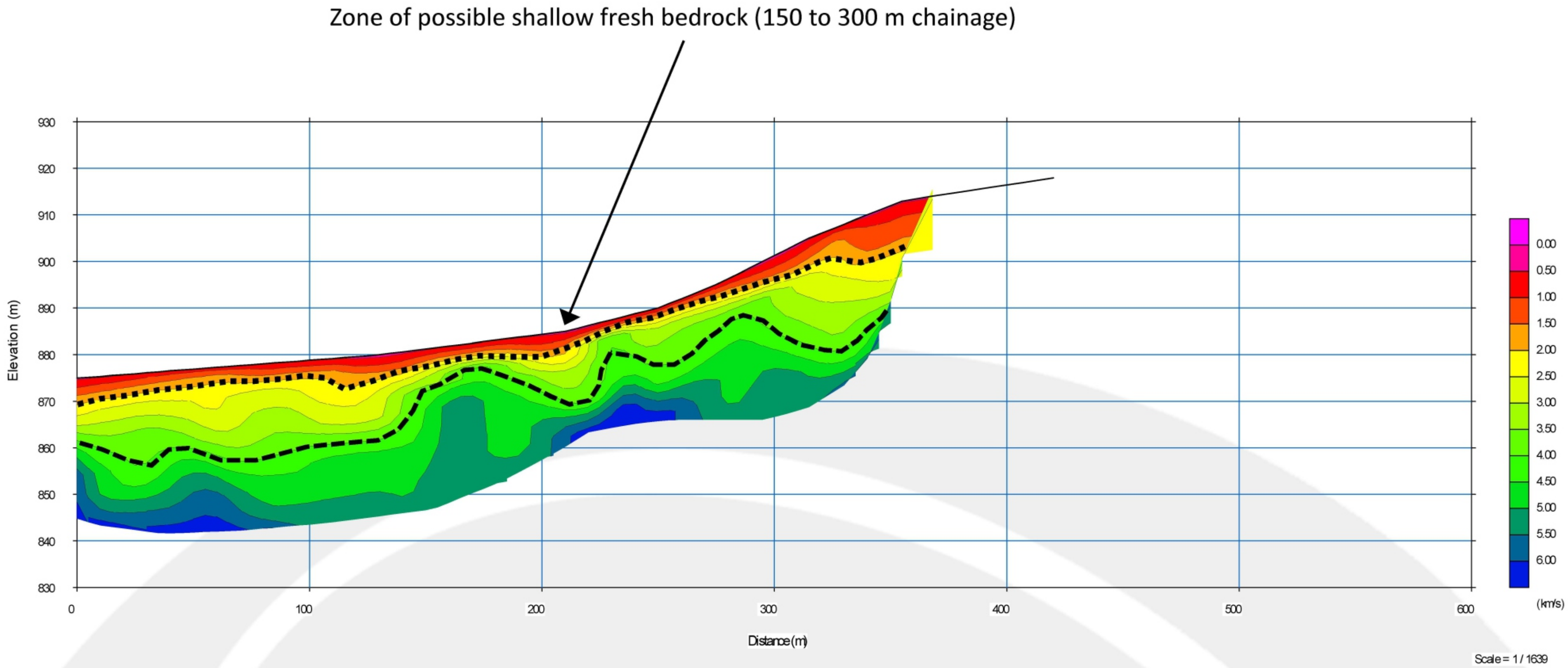

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FIGURE 20: Traverse N1N2 and N1AN2A Seismic Tomography Model (Balancing Dam Site)

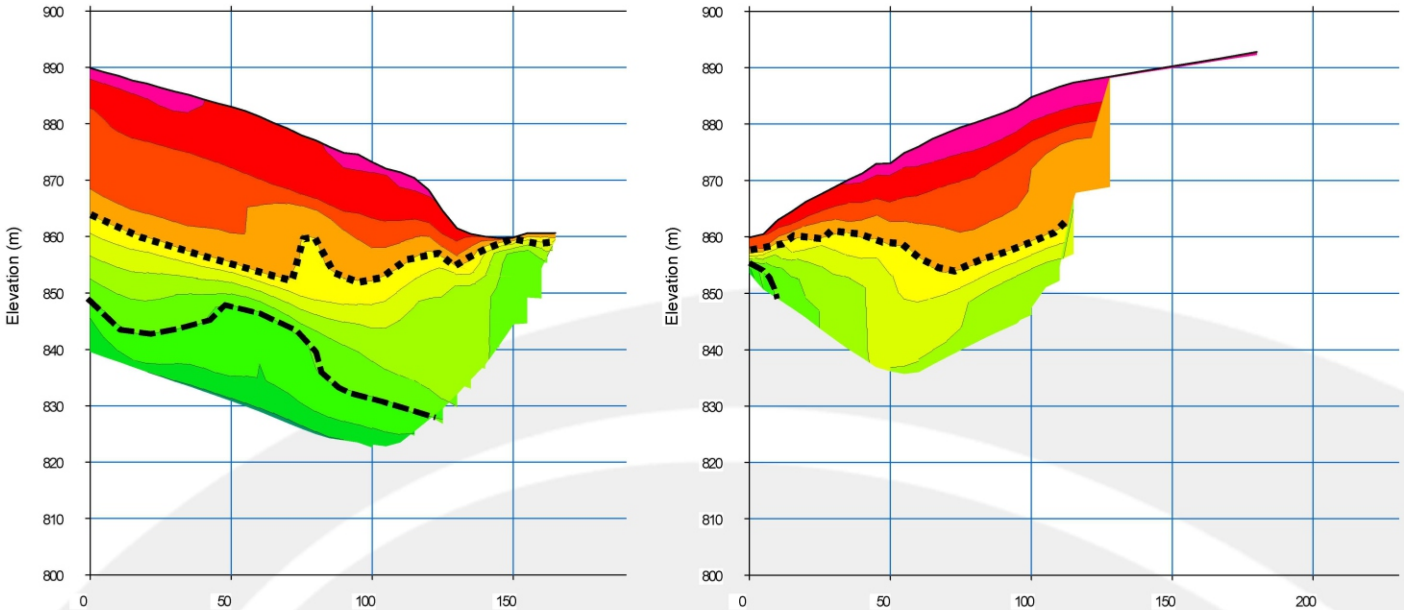

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FIGURE 21: Traverse G1G2 Seismic Tomography Model (Balancing Dam Site)

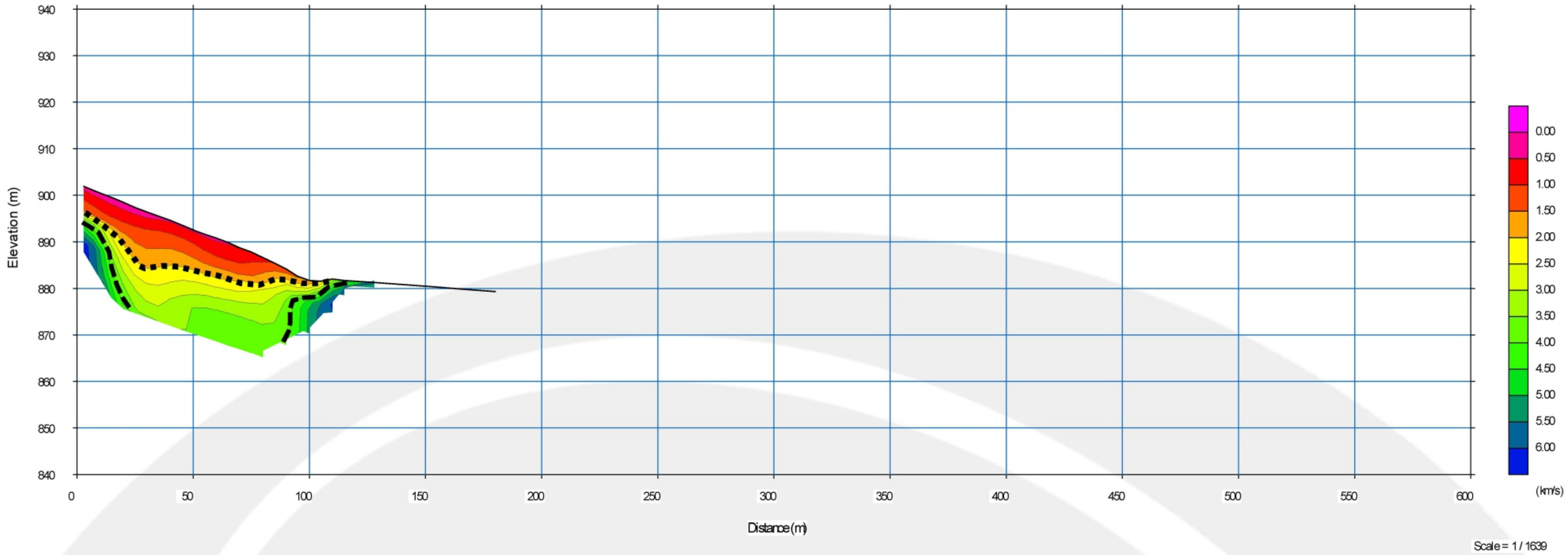

FIGURE 22: Traverse G2AG3A Seismic Tomography Model (Balancing Dam Site)

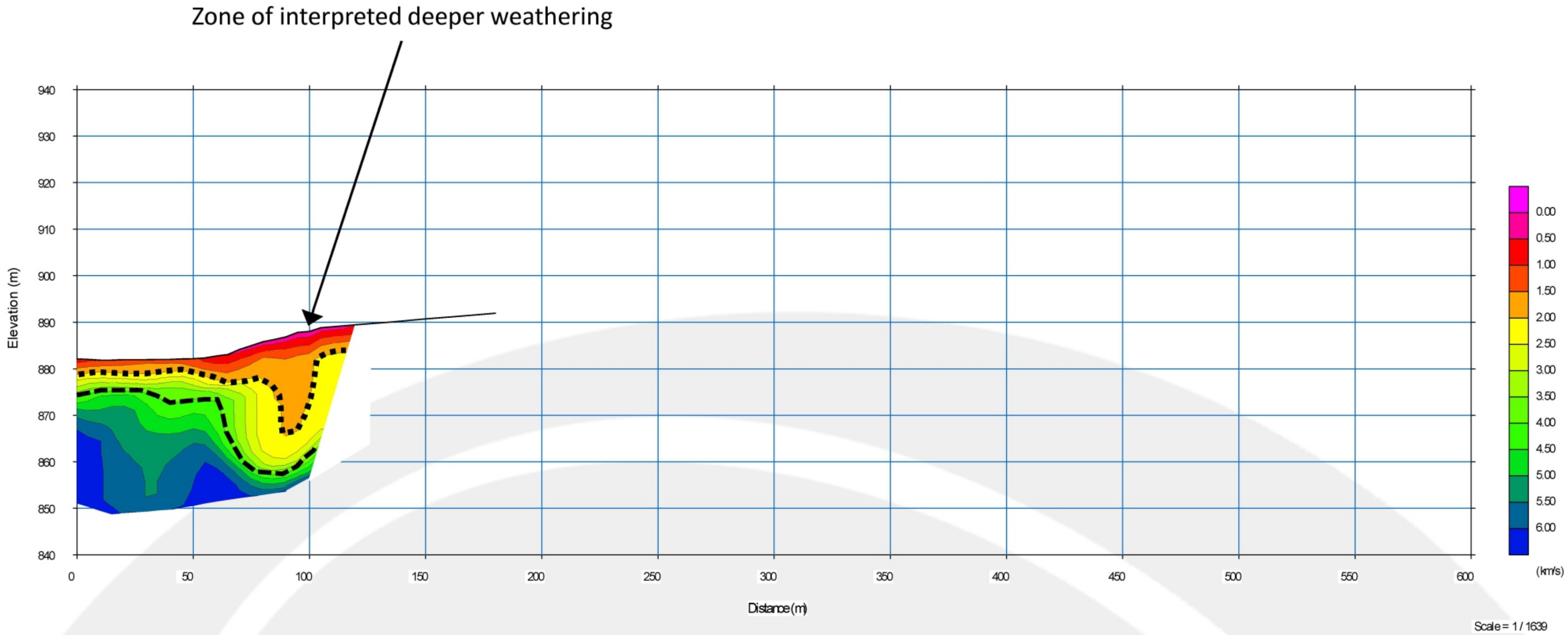

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FIGURE 23: Traverse G3BG4 Seismic Tomography Model
(Balancing Dam Site)

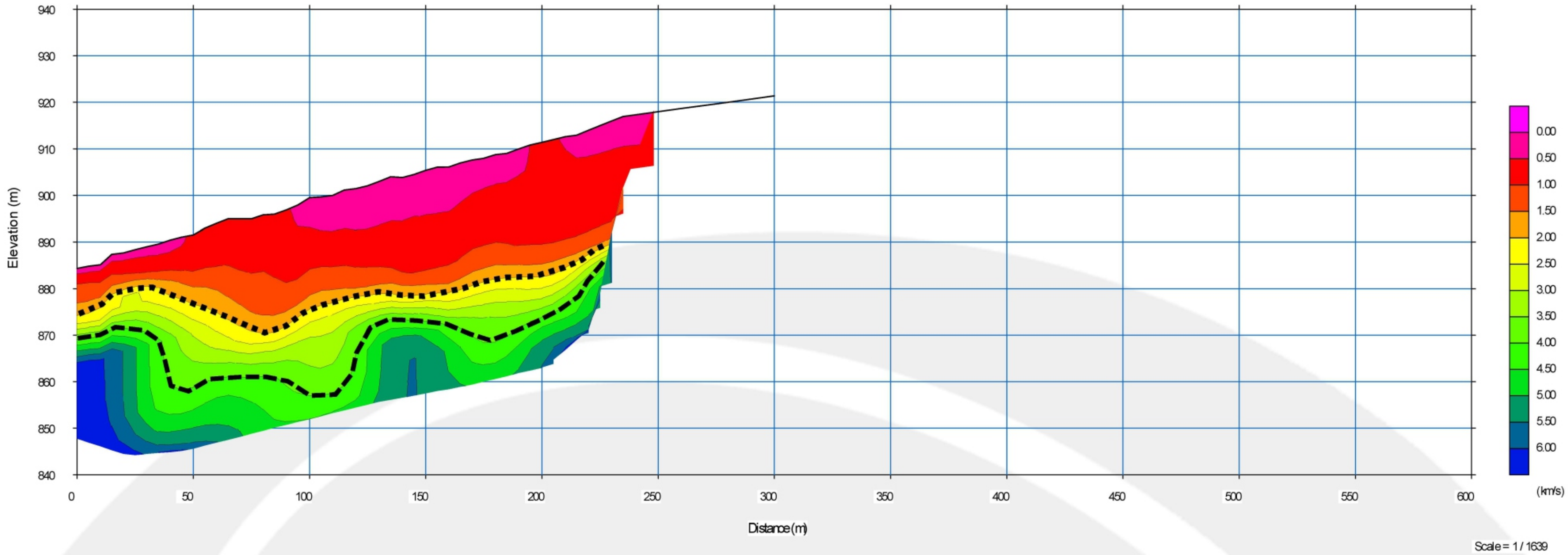

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FIGURE 24: Traverse O1O2 Seismic Tomography Model (Balancing Dam Site)

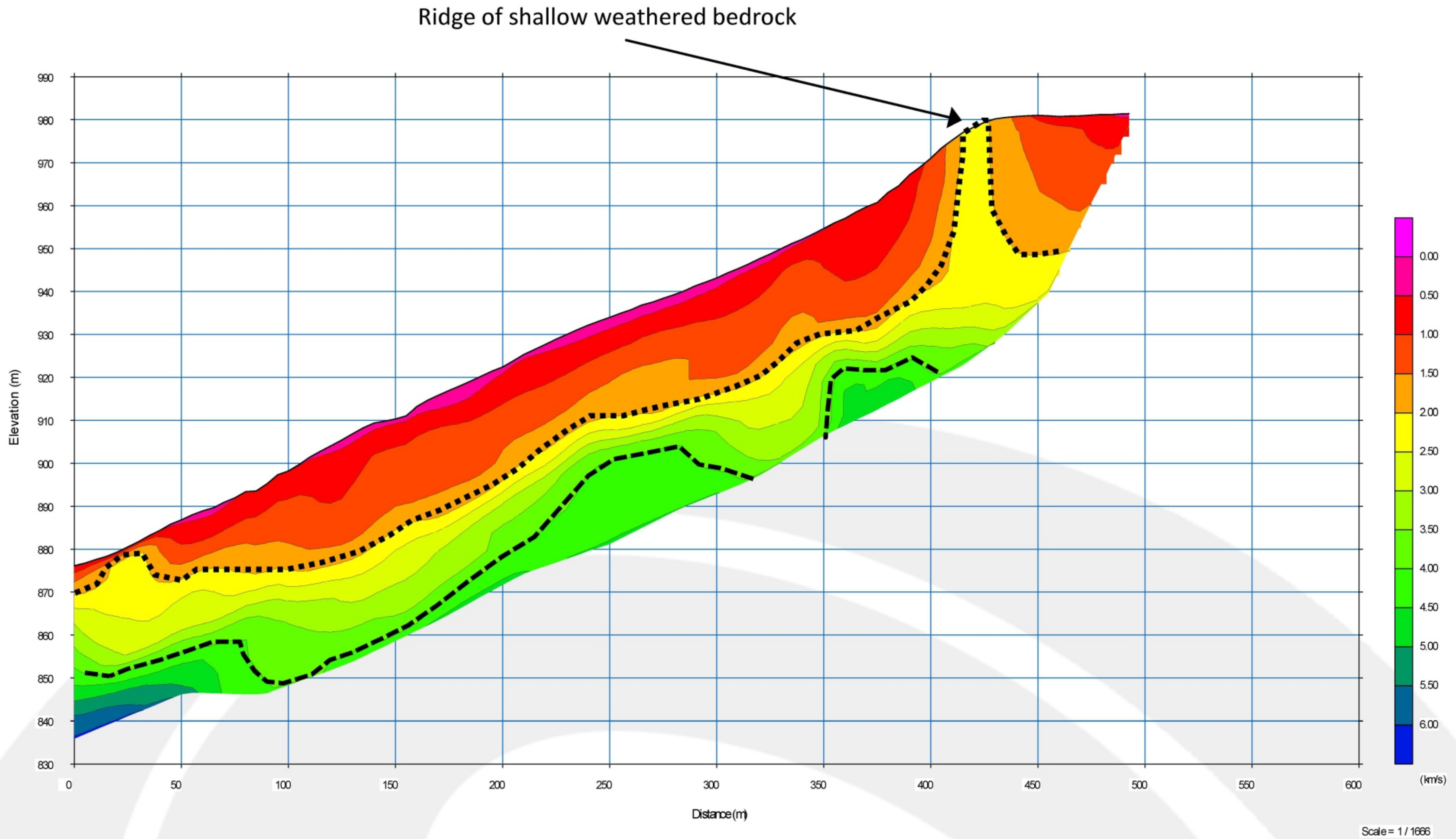

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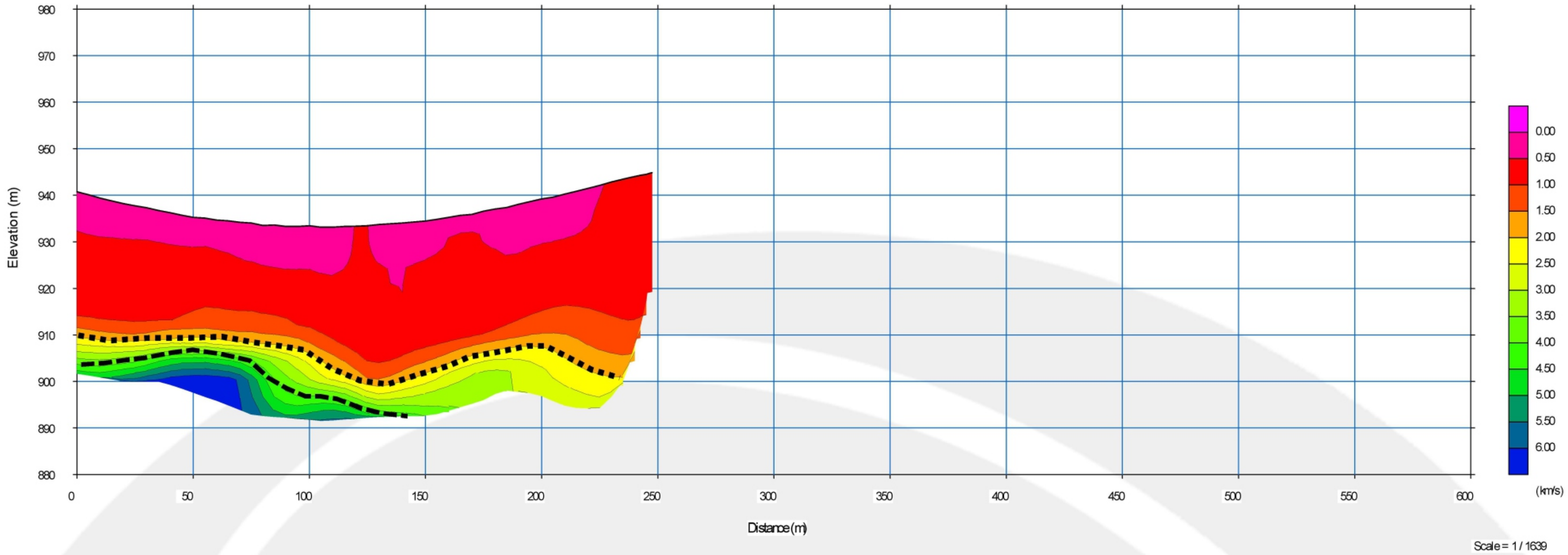
FIGURE 25: Traverse O3O4 Seismic Tomography Model (Balancing Dam Site)



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