AGP22013_01

Report on the Geophysical Investigation Phase II At Kinnegad Quarry Co. Westmeath For The Breedon group.

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THE FINDINGS OF THIS REPORT ARE THE RESULT OF A GEOPHYSICAL SURVEY USING NON-INVASIVE SURVEY TECHNIQUES CARRIED OUT AT THE GROUND SURFACE. INTERPRETATIONS CONTAINED IN THIS REPORT ARE DERIVED FROM A KNOWLEDGE OF THE GROUND CONDITIONS, THE GEOPHYSICAL RESPONSES OF GROUND MATERIALS AND THE EXPERIENCE OF THE AUTHOR. APEX GEOPHYSICS LTD. HAS PREPARED THIS REPORT IN LINE WITH BEST CURRENT PRACTICE AND WITH ALL REASONABLE SKILL, CARE AND DILIGENCE IN CONSIDERATION OF THE LIMITS IMPOSED BY THE SURVEY TECHNIQUES USED AND THE RESOURCES DEVOTED TO IT BY AGREEMENT WITH THE CLIENT. THE INTERPRETATIVE BASIS OF THE CONCLUSIONS CONTAINED IN THIS REPORT SHOULD BE TAKEN INTO ACCOUNT IN ANY FUTURE USE OF THIS REPORT.

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AUTHOR	**CHECKED**	**REPORT STATUS**	**DATE**
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CONTENTS

1. EXECUTIVE SUMMARY

APEX Geophysics Limited was requested by the Breedon Group to carry out a Phase II geophysical survey at Kinnegad Quarry, Co. Westmeath. Phase I survey was carried out in October 2021 with Phase II in January 2022. EM conductivity data, 13 ERT profiles and 8 seismic refraction profiles were recorded in total. Objectives were to assist in the hydrogeological assessment, provide information on karst features, screen the northwestern extension and map any faults/contacts between the Waulsortian/Lucan/Tober Colleen Formations. Survey area is c. 46 ha and consists of the existing quarry with greenfields to the northeast and settlement pond/scrub to the north. Topography generally ranges from c. 87 mOD on the surface to 70 mOD.

The Geological Survey of Ireland (GSI) map for the area shows massive unbedded Waulsortian Limestone. The Quaternary sediments map shows limestone till with raised peat in the southwest. The nearest karst features on the GSI database are c. 7 km north and 7 km south with significant karst features on site. The Waulsortian Limestone is classified as a 'Locally Important Aquifer – moderately productive only in Local Zones' (GSI).

Rotary percussive boreholes have been drilled to depths of between 5 and 20 m and summary logs have been plotted on the ERT profiles. The drilling results have been classified by SLR as clean limestone, intermittent clay and limestone, or karst infill. Water monitoring wells have also been drilled.

The contoured EM conductivity data has outlined a number of anomalous zones. Eight major EM anomalies occur and outline probable karst infill zones including the main partially excavated karst feature in the northwest as well as other local zones. Other minor EM anomalies which are generally indicative of near surface weathered rock with some clay infill or the presence of overburden material.

ERT profiles in the northwest extension area show 1 – 4 m thickness of interpreted weathered or fractured limestone over slightly weathered to fresh limestone. Seismic velocity indicates a massive/thickly bedded, very strong rock. Weak indications of localised weathering/change in lithology at c.30 m below floor level are present. Resistivities are typical of Waulsortian Limestone with no indication of a transition to Tober Colleen or Lucan Formations. A NE-SW trending fault has been outlined and can be seen in the northeastern face. ERT Profiles R4, R11, R12 and R13 in the northwest run across the main karst feature and show the main body to extend to around 30 m below the level of Bench 2, with some weaker expression to around 15 m below this. Width ranges from 10 m to 40 m. Seismic velocities indicate a generally firm to stiff clay infill.

ERT Profiles R5 and R6 in the southeast run perpendicular to the main karst feature and show it to extend to at least c. 30 m below Bench 1 (at least c. 40 mOD). The karst feature also appears to widen out at depth on R6. Both profiles have a near surface weathered/fractured zone which on R5 is thicker than elsewhere at 10-12 m. The seismic data indicates a generally strong/very strong rock away from the weathered/fractured zones.

The interpreted trend of the main karst feature based on the combined EM, ERT and borehole data has been drawn on Drawing AGP22013_03 and runs NW-SE for approximately 1120 m. The last 350 m to the southeast is based only on EM data and the location is less certain than further northwest. A number other karst features have also been outlined across the survey area.

Locations are proposed for confirmatory drilling. Boreholes located in the main high EM/low resistivity zones are likely to encounter clays and poor rock quality. Additional ERT profiling should be considered to investigate EM Zone B and the possible linear karst features at the southwestern ends of R5 and R6. The geophysical report should be reviewed after any further drilling.

2. INTRODUCTION

APEX Geophysics Limited was requested by the Breedon Group to carry out Phase II of a geophysical survey at Kinnegad Quarry, Co. Westmeath where information on the depth and extent of karst and weathering features are required to assist future quarry planning.

2.1 Survey Objectives

The objectives of the survey were to:

- assist in the hydrogeological evaluation of the site
- provide information on the clay filled karst feature running NW-SE through the northeastern part of the quarry
- screen the proposed extension area to the northwest for possible karst features and faults
- map any contact between the Waulsortian and Lucan Formations in the extension area
- provide targets for monitoring wells and for further investigation of karst features.

2.2 Site Background

The survey area extends to approximately 46 ha and is located approximately 3.0 km southwest of Kinnegad in Killaskillen townland. It consists of the existing quarry with greenfield areas to the northeast and the cement factory to the southwest (see Fig. 2.1). Site topography ranges from approximately 87 mOD at surface to c.70 mOD on Bench 1 to c.55 mOD on Bench 2. A recent (October 2021) high resolution orthophoto was supplied by the client. The Phase I geophysical survey was carried out in December 2021 and reported on in January 2022, (AGP21195 Report on Geophysical Survey of Kinnegad Quarry for the Breedon Group, January 2022.) This Phase II survey report incorporates the Phase I data and results.

Fig. 2.1: Site location map.

2.2.1 Geology

The Geological Survey of Ireland (GSI)1:100k Bedrock Geology map for the area (Fig. 2.2) shows that the site is underlain by Waulsortian Limestone, described as massive unbedded lime-mudstone with a transition at the extreme northwest into Tober Colleen calcareous shale and limestone conglomerate, followed by Lucan Formation, described as dark limestone and shale. Rock type to the southeast of the quarry is shown as Ballysteen Limestone. Bedding contacts between the formations run northeast-southwest (GSI, 2017a).

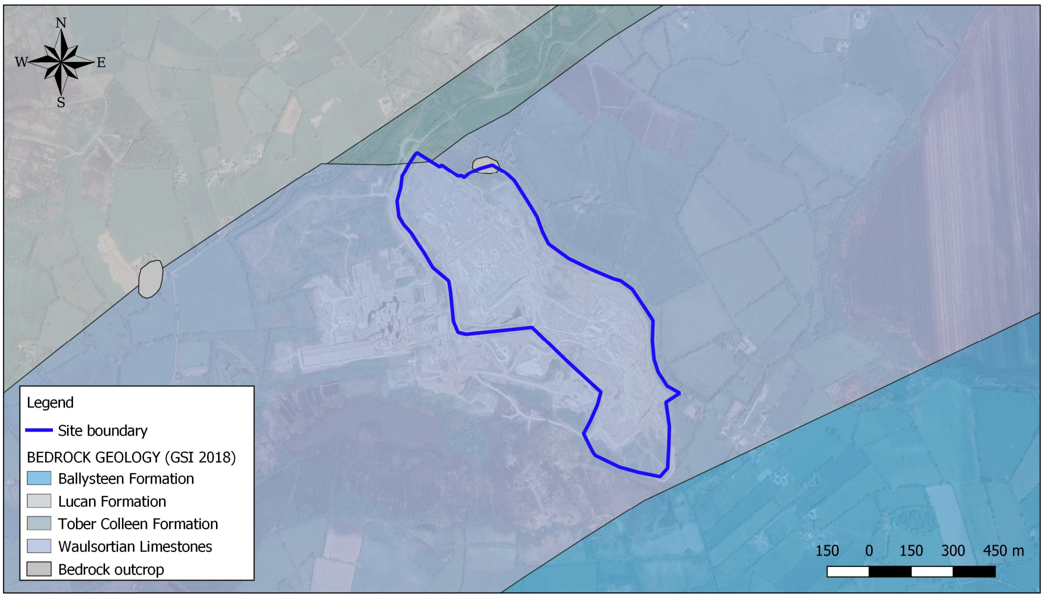

Fig. 2.2: Bedrock geology.

Fig 2.3A: View of partially excavated main karst feature, looking southeast .

Fig 2.3B: View of Bench 1/extension area looking northeast. Note dipping beds in centre of northeast face.

2.2.2 Soils

The GSI Quaternary sediments map for the area (Fig. 2.4) indicates that the site is within till derived from limestones in the centre and northeast, with cut over raised peat in the southwest, (GSI, 2017b).

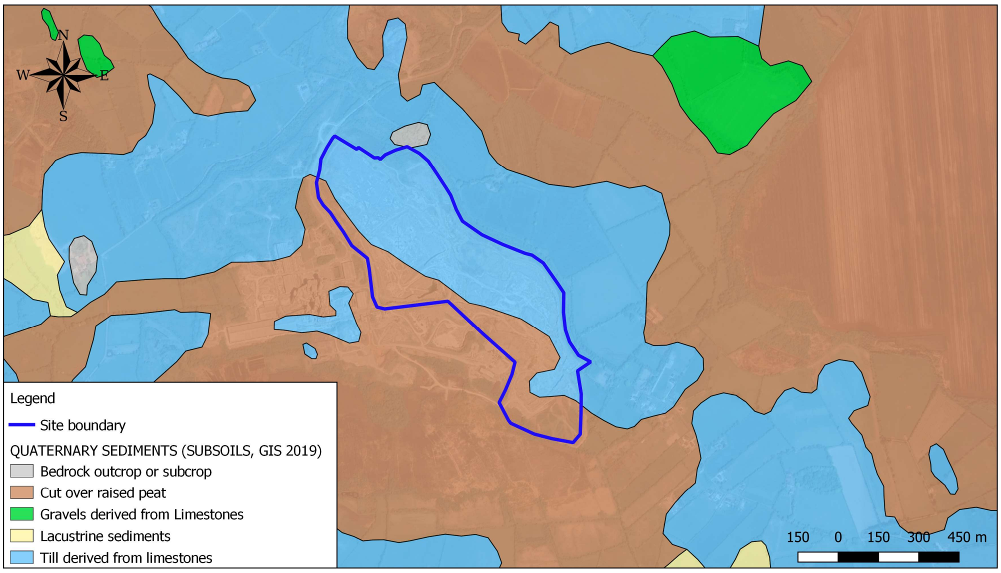

Fig. 2.4: Quaternary sediments.

2.2.3 Karst

The Waulsortian Limestones is known to be prone to solution weathering and karstification. The nearest karst features identified on the GSI karst database are springs, approximately 7 km to the north and 7 km to the south. Significant karst weathering features are evident on site.

2.2.4 Vulnerability

The groundwater vulnerability rating for the site (Fig. 2.5) is classified as generally ‘high’, with some ‘moderate’ to the southwest (GSI, 2017c).

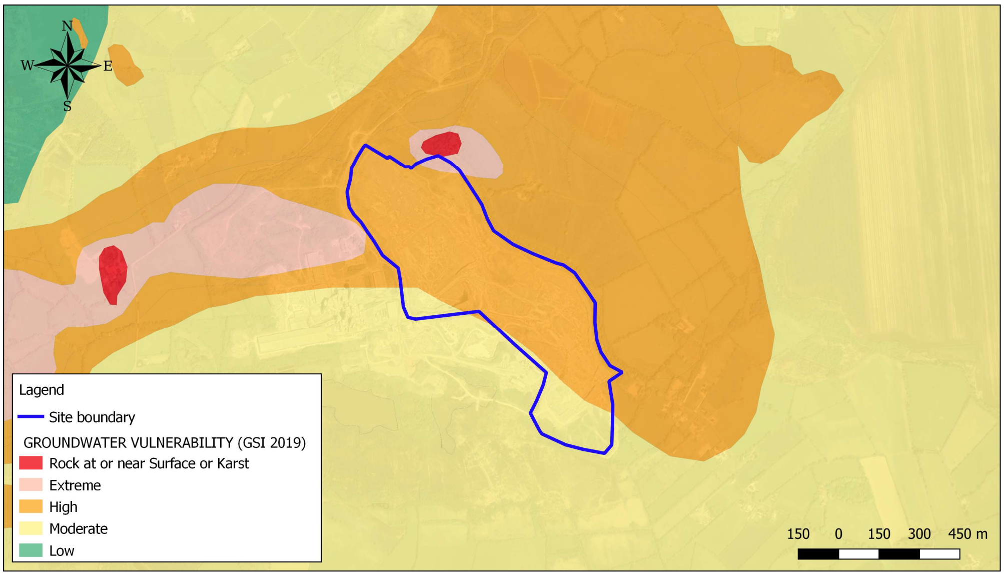

Fig. 2.5: Groundwater vulnerability.

2.2.5 Aquifer Classification

The Waulsortian Limestones in this area (Fig. 2.6) is classified as a ‘Locally Important Aquifer – moderately productive only in Local Zones’ (GSI).

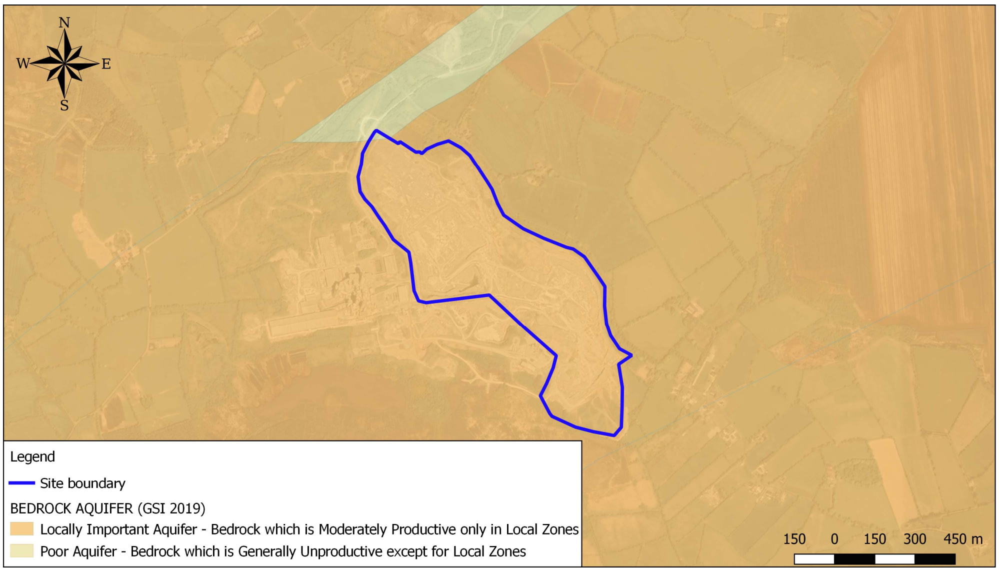

Fig. 2.6: The GSI aquifer map.

2.2.6 Historical Data

The historical 6 inch sheet for the area (Fig. 2.7) shows limestone outcrop/subcrop in the north of the site. Limestone is described as 'light grey, thick bedded, finely crystalline pale grey Limestone'.

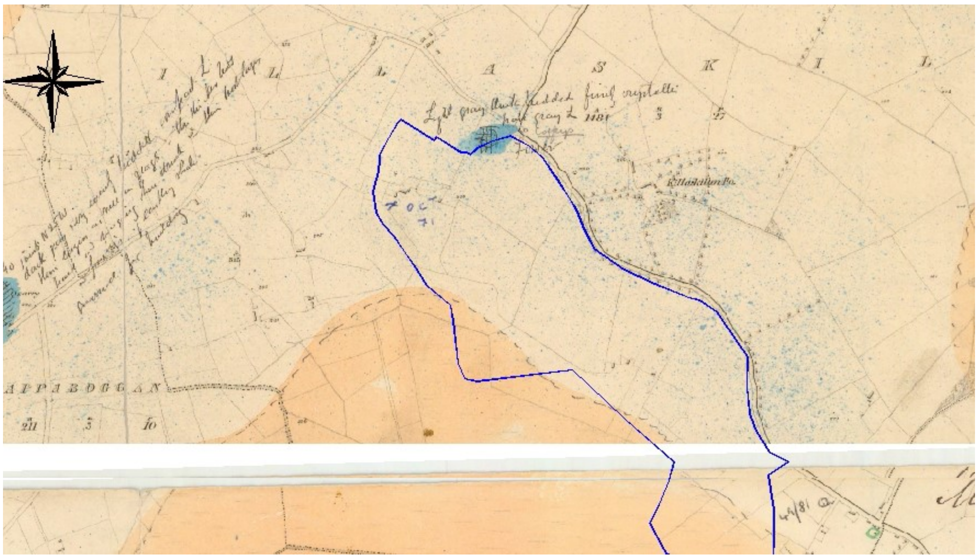

Fig 2.7: The historical 6 inch map.

2.2.7 Drilling

Seventy-six rotary percussive boreholes (21-KB-1 to 21-KD-76) have been drilled in the karst zone to depths of between 5 and 20 m. The locations are shown on Drawing AGP22013_01 and summary logs of adjacent boreholes have been plotted on the ERT profiles.

The drilling results have been classified in plan by SLR as clean limestone, intermittent clay and limestone, or karst infill, and the outline of zones of intermittent clay and limestone or karst infill have been plotted on Drawing AGP22013_03.

A well (ONGW14) was drilled recently in the extension area in the northweast and a short summary of the results made available. Strong rock was recorded between 1.3 and 4.8 m below floor level and from 7.5 m below floor level to 60 m below floor level. with clay, 'gravel' and cobbles between 4.8 and 7.5 m below floor level. This has been plotted as a summary log on ERT Profile R2 (see Drawing AGP22013_R2).

2.2.8 Phase I Geophysical Survey

The Phase I report has outlined the trend of the main karst feature based on the combined EM, ERT and borehole data and show it to run for at length of approximately 950 m along the northeastern side of the site. ERT Profile R4 shows the karst infill to extend to around 30 m below the level of Bench 2 or to around 25 mOD, with some weaker expression below this to around 5 mOD. Seismic velocities indicate a generally firm to stiff clay infill.

ERT profiles in the extension area show 1 – 4 m thickness of interpreted weathered or fractured limestone over slightly weathered to fresh limestone. Resistivities are typical of Waulsortian Limestone with no indication of a transition to Tober Colleen or Lucan Formations. Seismic velocity indicates a massive/thickly bedded, very strong rock. Weak indications of localised weathering/change in lithology at 30 m below floor level are present. A slight break at the northwestern end of R1 and at the southwestern end of R2 indicate a fault.

2.3 Survey Rationale

The investigation consisted of reconnaissance EM ground conductivity mapping with follow-up 2D Electrical Resistivity Tomography (ERT) and Seismic Refraction profiling:

EM ground conductivity mapping operates on the principle of inducing currents in conductive substrata and measuring the resultant secondary electro-magnetic field. The strength of this secondary EM field is calibrated to give apparent ground conductivity in milliSiemens/metre (mS/m). This technique will provide information on the shallow (0-6m below ground level) variation of the superficial deposits and outline the shallow bedrock.

ERT images the resistivity of the materials in the subsurface along a profile to produce a cross-section showing the variation in resistivity with depth, depending on the length of the profile. Each cross-section will be interpreted to determine the material type along the profile at increasing depth, based on the typical resistivities returned for Irish ground materials.

Seismic Refraction profiling measures the velocity of refracted seismic waves through the overburden and rock material and allows an assessment of the thickness and quality of the materials present to be made. Stiffer and stronger materials usually have higher seismic velocities while soft, loose or fractured materials have lower velocities. Readings are taken using geophones connected via multi-core cable to a seismograph. This method should allow us to profile the depth to the top of the bedrock, along profiles across the site.

As with all geophysical methods the results are based on indirect readings of the subsurface properties. The effectiveness of the proposed approach will be affected by variations in the ground properties. By combining a number of techniques it is possible to provide a higher quality interpretation and reduce any ambiguities which may otherwise exist. Further information on the detailed methodology of each geophysical method employed in this investigation is given in **APPENDIX B: DETAILED GEOPHYSICAL METHODOLOGY**.

3. RESULTS

The Phase I survey was carried out between the 10th and 11th October 2021 involving the collection of conductivity readings, 6 ERT profiles and 3 seismic refraction profiles. The Phase II survey was carried out between the 26th and 28th January 2022 involving the collection of additional conductivity readings, 8 ERT profiles and 5 seismic refraction profiles. The geophysical survey locations are indicated on Drawing AGP22013_01 (Appendix A).

3.1 EM Ground Conductivity Mapping

The EM ground conductivity results (Drawing AGP22013_02, Appendix A) are indicative of the bulk conductivity of the ground materials from 0 - 6.0m bgl. The recorded conductivity values range from 0.1 to 16 mS/m and have been generally interpreted in conjunction with the ERT and seismic data as follows:

Conductivity (mS/m)	Interpretation
0.0 – 2.0	LIMESTONE
2.0 – 6.0	CLAY and LIMESTONE
> 6	Thick overburden and/or karst infill (CLAY)

3.2 ERT

A total of fourteen resistivity profiles were recorded across the site (Profiles R1 – R14) between Phase 1 and Phase 2. Profiles R1- R3 and R7 – R11 were recorded and around the northwestern extension area to confirm rock type and screen for any changes with depth or the presence of weathered zones. Profiles R4 – R5, part of R11 and R12 – R14 were recorded across the trend of the main karst feature (R4 was run obliquely in order to obtain maximum depth penetration). Interpreted cross sections were compiled for all profiles and are presented on Drawings AGP22013_R1-R14.

The resistivity values recorded at this site ranged from 20 – 20,000 Ohm-m and have been interpreted as follows:

Resistivity (Ohm-m)	Interpretation
20 - 350	OVERBURDEN - completely weathered LIMESTONE with CLAY infill
350 – 1,000	Highly weathered/ karstified LIMESTONE with CLAY infill
1,000- 1,500	Moderately weathered/ karstified LIMESTONE with CLAY infill
1,500- 20,000	Slightly weathered – fresh LIMESTONE

3.3 Seismic refraction profiling

Eight seismic refraction profiles (S1-S8) were recorded to check rock quality and the degree of weathering. The locations are on Drawing AGP22013_01 and results are included on Drawings AGP22013_R1, AGP22013_R9, AGP22013_R10, AGP22013_R13, and AGP22013_R14 and in Appendix C.

The P-wave seismic velocities have been interpreted as follows:

Layer	P-wave Velocity (m/s)	Interpretation
1	300 - 500	Soft-firm overburden/fill
2	1,000 – 1,200	Overburden/fill and completely - highly weath. LIMESTONE with CLAY infill (firm-stiff).
3	1,500 – 1,900	Completely - highly weathered LIMESTONE with CLAY infill (stiff).
4	4,100 – 5,500	Slightly weathered – fresh LIMESTONE

4. DISCUSSION

The integrated geophysical results and interpretation are presented on Drawings AGP22013_R1 to AGP22013_R14 and the results are summarised on Drawing AGP22013_03. The outline of the drilling results showing intermittent clay and limestone, or karst infill as classified by SLR has been plotted in yellow on Drawing AGP22013_03.

EM Conductivity

EM values within a limestone quarry with no overburden or clay filled features present would generally be low (0.1 – 2 mS/m). The contoured EM conductivity data within the quarry has outlined a number of zones exceeding this range. Thresholds of > 2mS/m and > 6mS/m have therefore been taken to indicate minor and major anomalies respectively.

The Phase II EM data recorded at the original ground level on the northwest perimeter of the quarry and around the settlement pond show elevated values at a number of locations. EM conductivity values in areas of thin limestone till (overburden) are normally in the range 2-6 mS/m. Values greater than this usually indicate thicker overburden or a change to predominantly clayey or silty material.

The minor anomalies are generally quite broad and are concentrated along the northeastern side of the quarry with only two very localised zones in the northwest extension area. Given that the depth range of the EM meter is 0 – 6 m bgl these anomalies are mostly indicative of near surface weathered rock with some clay infill or the presence of overburden material. The weathering and clay infill or overburden may extend below 6m in some cases. The major anomalies are also located along the northeastern side of the quarry and have been numbered A-H on Drawing AGP22013_03. They are discussed in detail below.

Anomaly A is around 20m wide and is associated with the partially excavated main karst feature. The NW-SE trending linear EM anomaly outlines the extent of the karst feature at this point. It coincides at its southeastern end with the low resistivity zone on ERT profile R4. The outline also correlates well with where karst infill was recorded on the drilling, but not with the wider intermittent clay and limestone results.

Anomaly B occurs further to the southeast and is slightly offset to the southwest. It shows a correlation with the intermittent clay and limestone recorded on the drilling in this area, and also with the low resistivity feature at the southern end of ERT profile R5. This zone is open to the south.

Anomaly C is a small, apparently isolated, zone on the northeastern boundary. There are no boreholes or ERT profiles adjacent.

Anomaly D is a larger area located at the southern end of the survey area. No boreholes or ERT profiles are adjacent. The zone is open to the northwest, north and east and may be more extensive.

Anomaly E is located immediately west of the Bench 1 face in the northwestern extension area at the original ground level. It coincides with the low resistivity zones at the end of ERT Profile R10 and the start of ERT Profile R11. It also coincides with the low velocity zone on seismic profile S5 which is between 9 and 14 m thick and has been interpreted as a zone of completely to highly weathered limestone with clay infill. Evidence for this zone can also be seen in the photograph of the face in Fig. 4.1 below.

Fig. 4.1 Looking west at western face in northwest extension area in vicinity of EM anomlay E.

Anomaly F is located immediately northwest of the Bench 1 face in the northwestern extension area at the original ground level. There is no corresponding zone of weathering or change in overburden thickness on ERT profile R11 and the anomaly appears due to a localised change in soil type to a more clay rich material.

Anomaly G is a large area to the north of the settlement pond and is associated with a thickening of overburden and possible karst fill at the northeastern end of R11 and the northwestern end of R14. It is in line with the trend of the main exposed karst feature in the quarry and shows it to widen significantly to around 40m at this point.

Anomaly H is a large area to the southeast of the settlement pond and coincides with a thickening of overburden and possible karst fill at the southwestern end of R13. It is also in line with the trend of the main exposed karst feature in the quarry.

ERT Profiles.

ERT Profiles **R1, R2, R3, R7, R8 and R9** are located in the extension area in the northwest. Each profile has an intermittent upper layer 1 – 4 m thick of low resistivity material interpreted as weathered or fractured limestone over generally consistent slightly weathered to fresh limestone. The upper weathering/fracturing may be due to overbreak from blasting and joint relaxation. The weathering/fracturing thickens at 130 m along R7 and at 60 m along R8 which coincide with localised increases in EM conductivity and are interpreted as due to small scale infilled karstic features.

Resistivities on R1, R2, R3 R7, R8 and R9 are typical of Waulsortian Limestone with no indication of a transition to lower resistivity Tober Colleen or Lucan Formation. A seismic velocity of 5400 m/s on S1 indicates a massive/thickly bedded very strong rock. Strong rock was recorded on well ONGW14 between 1.3 and 4.8 m below floor level and from 7.5 m below floor level to 60 m below floor level.

Breaks in resistivity at the northwestern end of R1, at the northwestern end of R9 and a slight break at the southwestern end of R2 indicate a fault trending NE-SW. The interpreted fault location is shown on Drawing AGP22013_034 and in Fig. 4.2 below, and may extend as far as 85 m northwest along R14. The clay, 'gravel' and cobbles encountered between 4.8 and 7.5 m on well ONGW14 may have been where the well intercepted this fault.

Seismic profile S4 records a relatively high seismic velocity of 4,500 m/s for the bedrock in the vicinity of the fault which indicates that fracturing is probably localised and minor.

Fig. 4.2 Looking north at northeast face in northwest extension area. Interpreted fault location is shown by arrow.

There is a slight drop is resistivity at around 30 – 35 m below floor level (c. 40 - 35 mOD) on R1, R2 R3, R7 and R9 which could indicate some localised weathering or a change in lithology at depth.

ERT **Profile R4** runs obliquely across the main karst feature and shows it to extend to around 30 m below the level of Bench 2 or to around 25 mOD with some weaker expression below this level to around 5 mOD. The width of the karst zone is exaggerated due the angle of intersection but when looked at in plan with the EM data it is between 20 – 25 m wide at this point. R4 also has an intermittent near surface weathered/fractured zone 2 – 5 m thick. Seismic Profile S3 at the southwestern side of the main indicates a firm to stiff clay infill.

ERT Profiles **R11, R12, R13 and R14** all intersect the karst zone to the northwest of R4 and show the main feature to widen to around 40m on R11 with a possible additional 45m of highly weathered material to the southwest of the main zone. The deepest penetration of this group of profiles in on R11 at c.30 mOD and the karst feature is still strongly present at this point. Seismic profiles S7 and S8 indicate that the karst infill material is generally stiff – very stiff. There is also some thickening of possible infill material at the northeastern ends of R12 and R13 and this has been outlined on Drawing AGP22013_03.

ERT **Profiles R10 and R11** both show a low resistivity zone at the western side of the northwestern extension area at the original ground level. This is confirmed by seismic profile S5 which shows low velocity material to a depth of between 9 and 14 m bgl (c. 70 mOD). There is some expression of this weathered zone in the face (see Fig. 4.1 above).

ERT **Profiles R5 and R6** run perpendicular to the main karst feature and both show it to extend to below the depth range of the profiles (c. 30 m below Bench 1 floor or to at least 40 mOD). The karst feature is strongest on R6 and also appears to widen out at depth to 10 – 15 m. Both profiles have a near surface weathered/fractured zone. The surface weathered/fractured zone on R5 is thicker than elsewhere at 10-12 m. Boreholes 21-KD-65 and 21-KD-66 show a correlation with the upper 3-4 m of weathered material. Both logs mention water strikes, which along with some fracturing may be the reason for the thicker low resistivity zone on R5. Both R5 and R6 also have a localised shallow resistivity layer at the northeastern end which correlates with rock and softer material on the boreholes. The seismic data on S2 indicates a generally strong/very strong rock away from the weathered/fracture zones.

The interpreted outline of the main karst feature based on the combined EM, ERT and borehole data has been drawn on Drawing AGP22013_03 and runs for approximately 1120 m parallel to the northeastern side of the quarry. The outline of the last 350 m to the southeast is based on EM data only and is less certain than further northwest. A number of other probable karst features have also been outlined.

Seismic Profiles.

Seismic profiles S3 and S6 were recorded over the main karst feature in an attempt to bottom out the infill. An increase in velocity is noted at 57 mOD but it is felt that this is too shallow and is refracted off the side wall. The infill material is noted as stiff.

Both S5 on R10 and S8 on R13 indicate competent rock at shallower levels than the corresponding ERT data which indicates highly weathered rock. This ambiguity may be due to the relatively narrow nature of the karst features which gives rise to the seismic signal being refracted off the side walls rather than the bottom of the feature. Until confirmed by drilling it is considered prudent to use the deeper extent of the clay infill as indicated by the ERT profiles.

5. RECOMMENDATIONS

Locations are proposed for additional confirmatory drilling. PBH1 – PBH7 and PBH10 – 12 are located in the main high EM/low resistivity zones/infilled karst zones and if drilled will require an alternative to rotary percussive as clays and poor rock quality are to be expected at all of these locations.

PBH8 – PBH9 are located along the possible fault in the northwestern extension zone.

No.	Easting	Northing
PBH1	657327.2	743167.3
PBH2	657440.6	743019.3
PBH3	657450.4	742855.6
PBH4	657546.7	742854.9
PBH5	657548.7	742792.7
PBH6	657793.3	742721.5
PBH7	657801.4	742522.6
PBH8	657072.9	743298.5
PBH9	657007.5	743171.9
PBH10	657250.6	743240.4
PBH11	657195.0	743308.9
PBH12	657092.0	743449.3

Table 5.1 Proposed borehole locations

Some additional ERT profiling should be considered to investigate EM Zone B and the possible linear karst features at the southwestern ends of R5 and R6.

The geophysical report should be reviewed after any further drilling.

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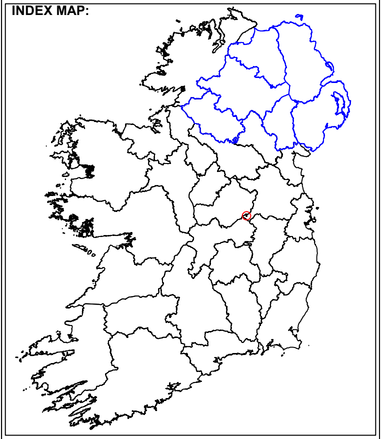
APPENDIX A: DRAWINGS

The information derived from the geophysical investigation is presented in the following drawings:

AGP22013_01	Geophysical Locations	1:6000	@ A4
AGP22013_02	EM Conductivity Results	1:6000	@ A4
AGP22013_03	Summary Map	1:6000	@ A4
AGP22013_R1	Results & Interpretation – ERT R1 & Seismic profile S1	1:1000	@ A4
AGP22013_R2	Results & Interpretation – ERT R2	1:1000	@ A4
AGP22013_R3	Results & Interpretation – ERT R3	1:1000	@ A4
AGP22013_R4	Results & Interpretation – ERT R4	1:1500	@ A4
AGP22013_R5	Results & Interpretation – ERT R5	1:1000	@ A4
AGP22013_R6	Results & Interpretation – ERT R6	1:1000	@ A4
AGP22013_R7	Results & Interpretation – ERT R7	1:1000	@ A4
AGP22013_R8	Results & Interpretation – ERT R8	1:1000	@ A4
AGP22013_R9	Results & Interpretation – ERT R9 & Seismic profile S4	1:1000	@ A4
AGP22013_R10	Results & Interpretation – ERT R10 & Seismic profile S5	1:1500	@ A4
AGP22013_R11	Results & Interpretation – ERT R11	1:1000	@ A4
AGP22013_R12	Results & Interpretation – ERT R12	1:1000	@ A4
AGP22013_R13	Results & Interpretation – ERT R13 & Seismic profile S8	1:1000	@ A4
AGP22013_R14	Results & Interpretation – ERT R14 & Seismic profile S7	1:1000	@ A4

GEOPHYSICAL LOCATIONS
SCALE 1:6000

INDEX MAP:



LEGEND:

	Site boundary
++++	EM conductivity reading
R1	2D resistivity profile
S1	Seismic refraction profile
21-KD-45	Rotary percussive borehole
ONGW14	Well

The information displayed here is to be used in conjunction with AGP21195_01 Report on a Geophysical Investigation at Kinnegad Quarry for THE BREEDON GROUP., APEX Geophysics Ltd. 7th February 2022.

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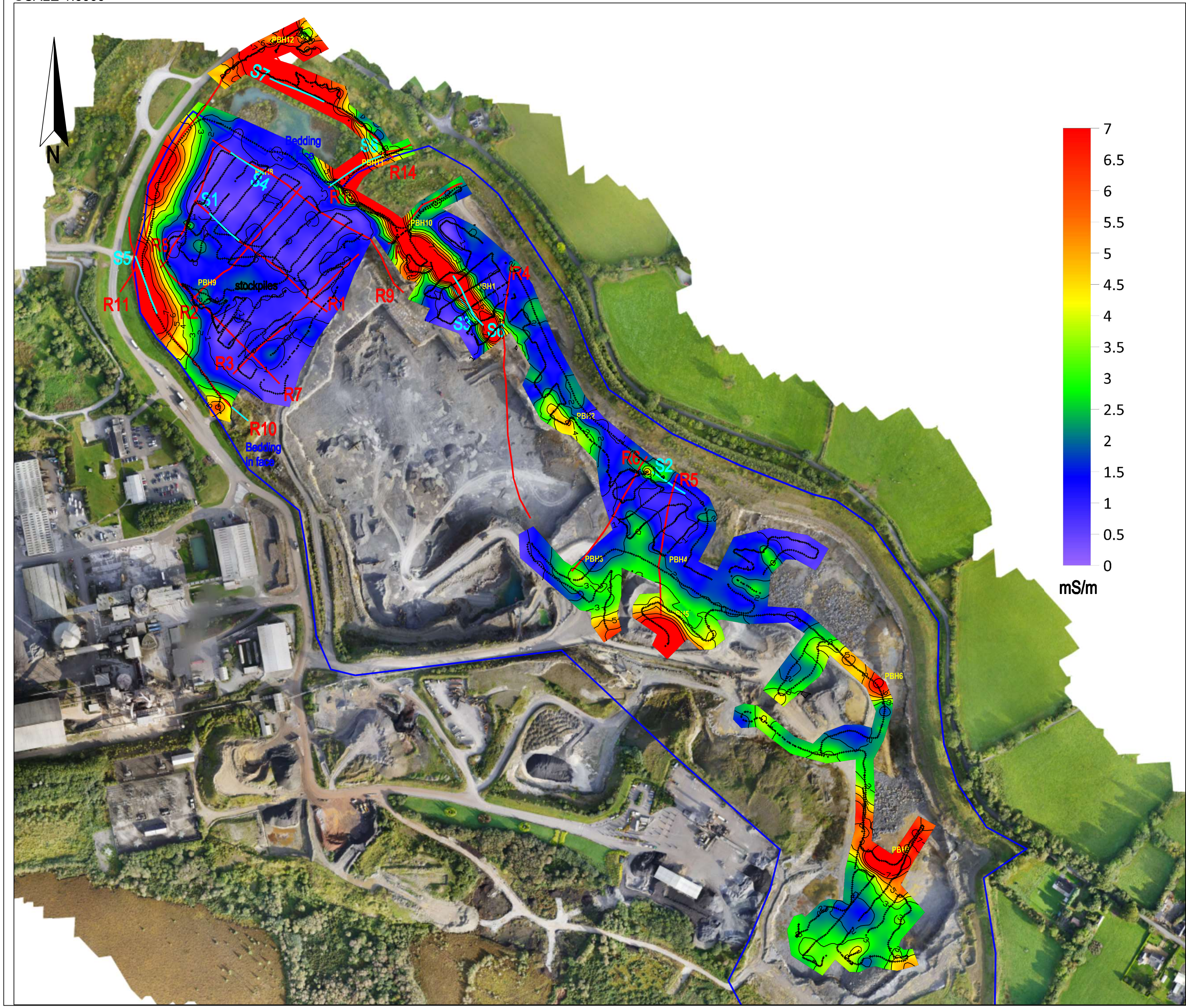
www.apexgeophysics.ie

PROJECT:	KINNEGAD QUARRY GEOPHYSICAL SURVEY PHASE II
CLIENT.:	THE BREEDON GROUP
DRAWING NO:	AGP21195_01
SCALE:	AS INDICATED @ A4
DATE:	07-02-2022

Version:	Date:	Drawn By:	Checked:
001	07-02-2022	POC	TL

EM CONDUCTIVITY RESULTS
SCALE 1:6000



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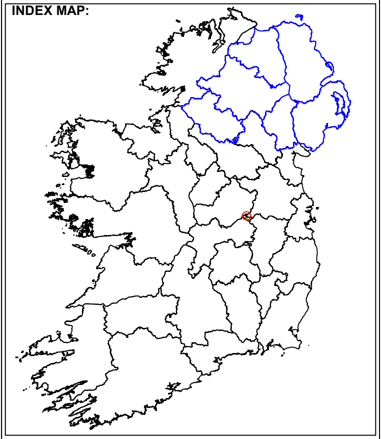

LEGEND:

Site boundary
++++ EM conductivity reading
R1 2D resistivity profile
S1 Seismic refraction profile

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PROJECT:	KINNEGAD QUARRY GEOPHYSICAL SURVEY PHASE II
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DRAWING NO:	AGP21195_02
SCALE:	AS INDICATED @ A4
DATE:	07-02-2022

Version:	Date:	Drawn By:	Checked:
001	07-02-2022	POC	TL

SUMMARY INTERPRETATION
SCALE 1:6000

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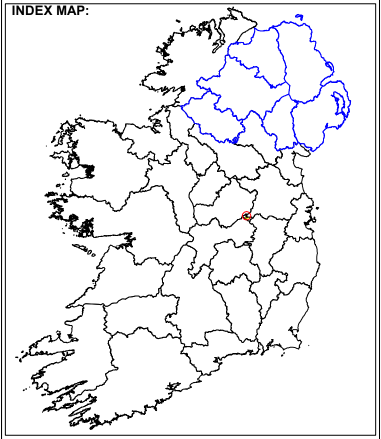

LEGEND:

- ERT profile
- Main EM Anomaly
- Minor EM Anomaly
- Karst Fill/Intermittent Clay from Drilling Summary
- Interpreted Location of Karst Features
- Inferred Fault from ERT profiles
- Proposed Borehole

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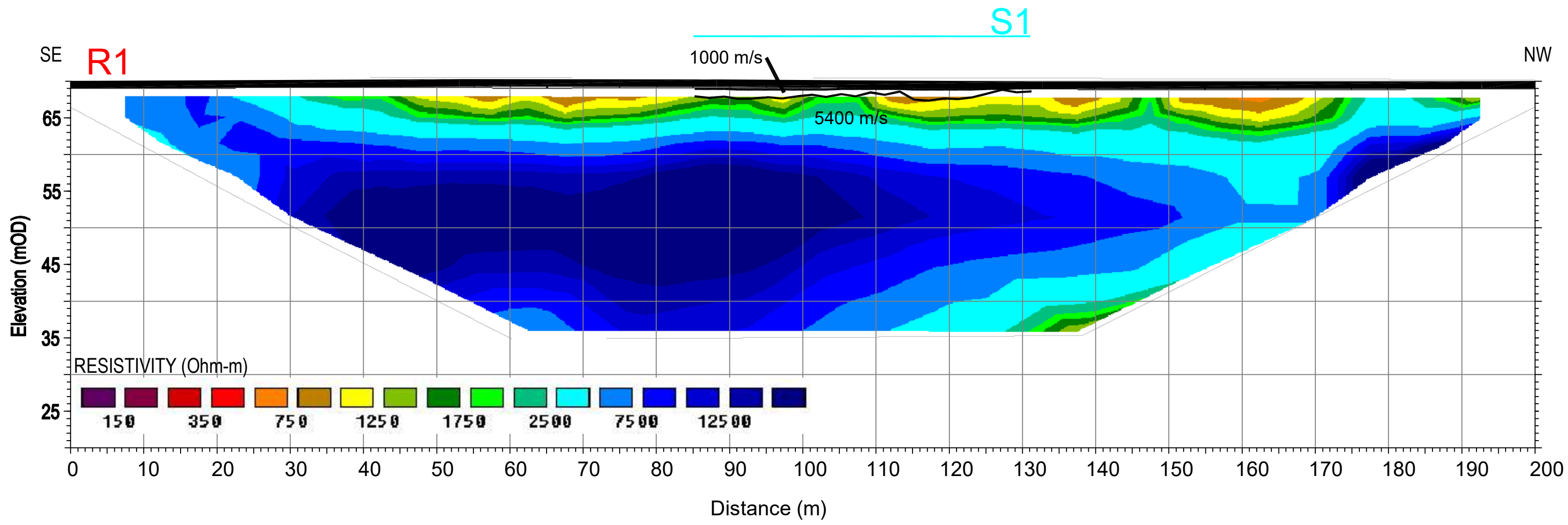
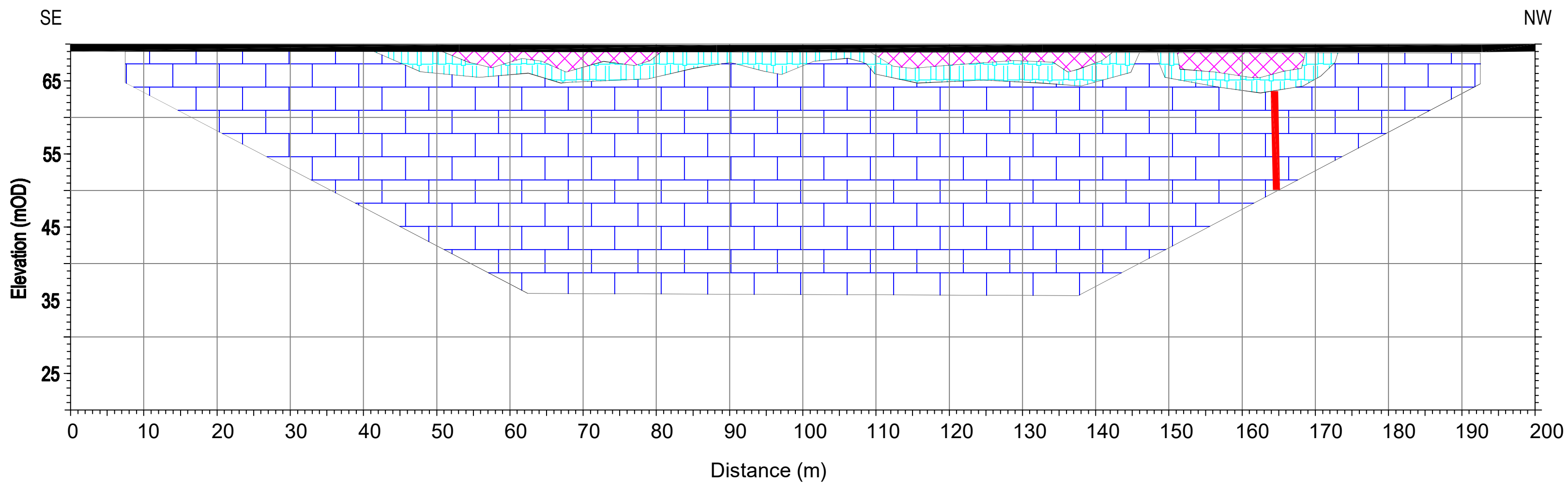
PROJECT:	KINNEGAD QUARRY GEOPHYSICAL SURVEY PHASE II
CLIENT.:	THE BREEDON GROUP
DRAWING NO:	AGP21195_03
SCALE:	AS INDICATED @ A4
DATE:	07-02-2022

Version:	Date:	Drawn By:	Checked:
001	07-02-2022	POC	TL

RESISTIVITY PROFILE R1 AND SEISMIC PROFILE S1

SCALE 1:1000





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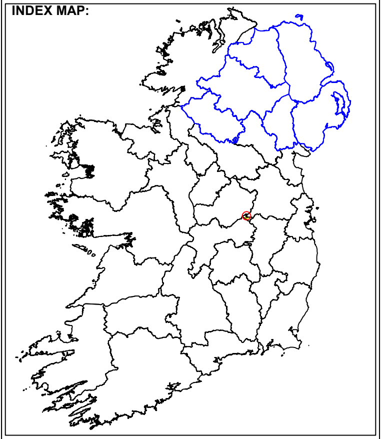

LEGEND:

OVERBURDEN - completely weathered LIMESTONE with clay infill

Highly weathered/ karstified/fractured LIMESTONE with clay infill

Mod, weathered/karstified/ fractured LIMESTONE with clay infill

Slightly weathered - fresh LIMESTONE

Possible Fault

1-KD-65 Borehole summary log

1400 m/s Seismic boundary and P-wave velocity

S1 Seismic Profile intersection

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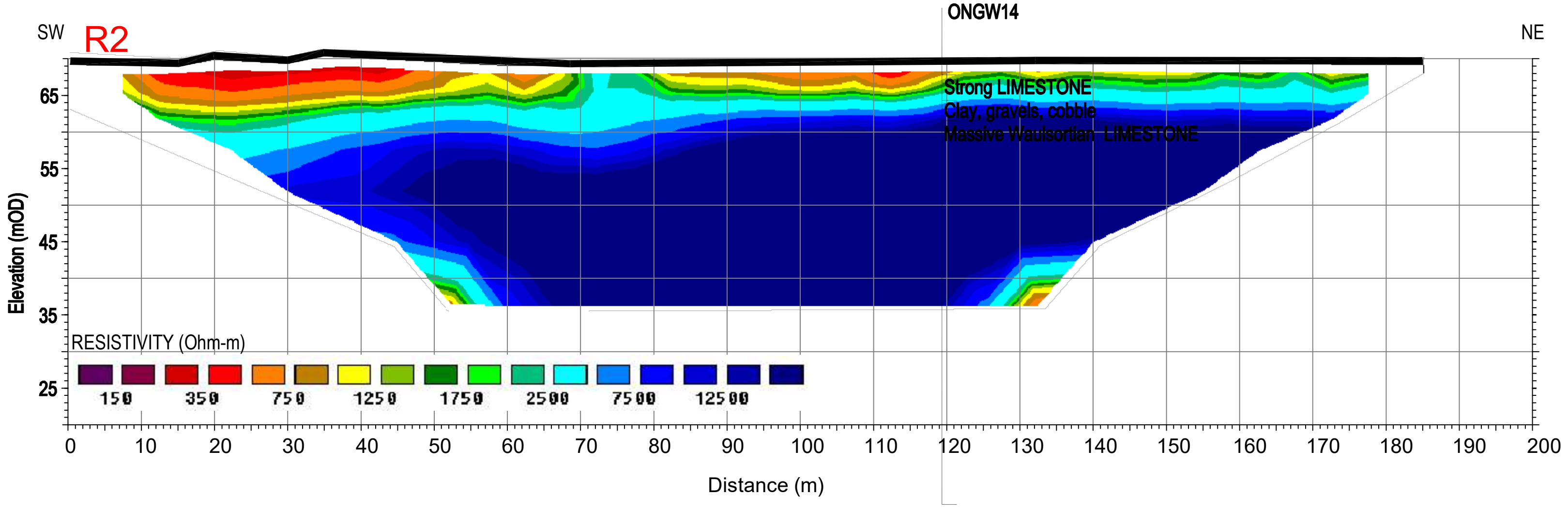
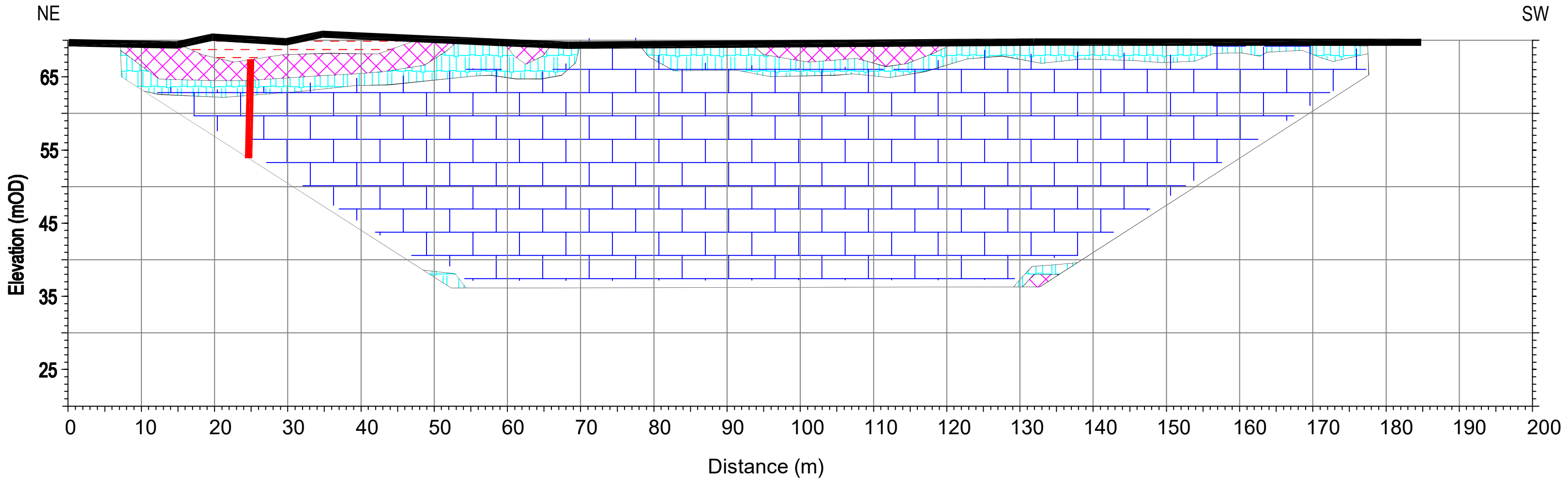
DRAWING NO:	AGP21195_R1
SCALE:	AS INDICATED @ A4
DATE:	07-02-2022

Version:	Date:	Drawn By:	Checked:
001	07-02-2022	POC	TL

RESISTIVITY PROFILE R2

SCALE 1:1000





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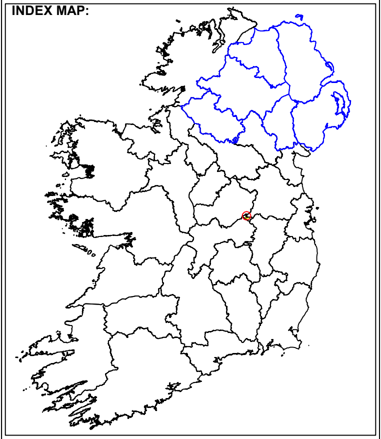

LEGEND:

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- Possible Fault
- 21-KD-65 Borehole summary log
- 1400 m/s Seismic boundary and P-wave velocity
- S1 Seismic Profile intersection

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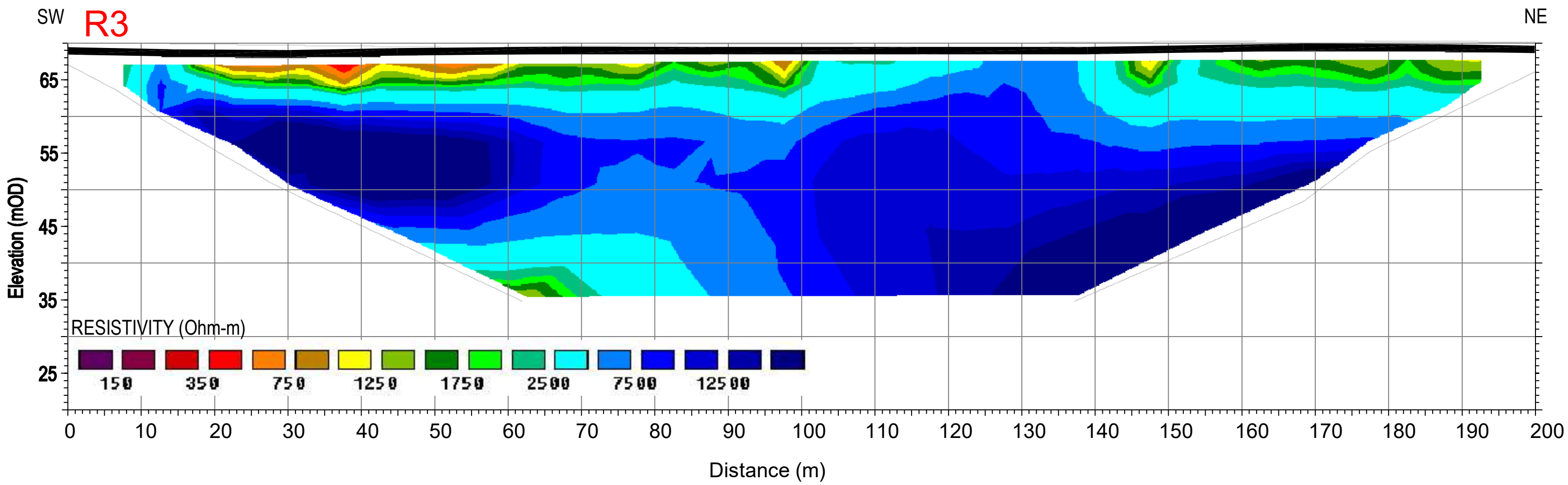
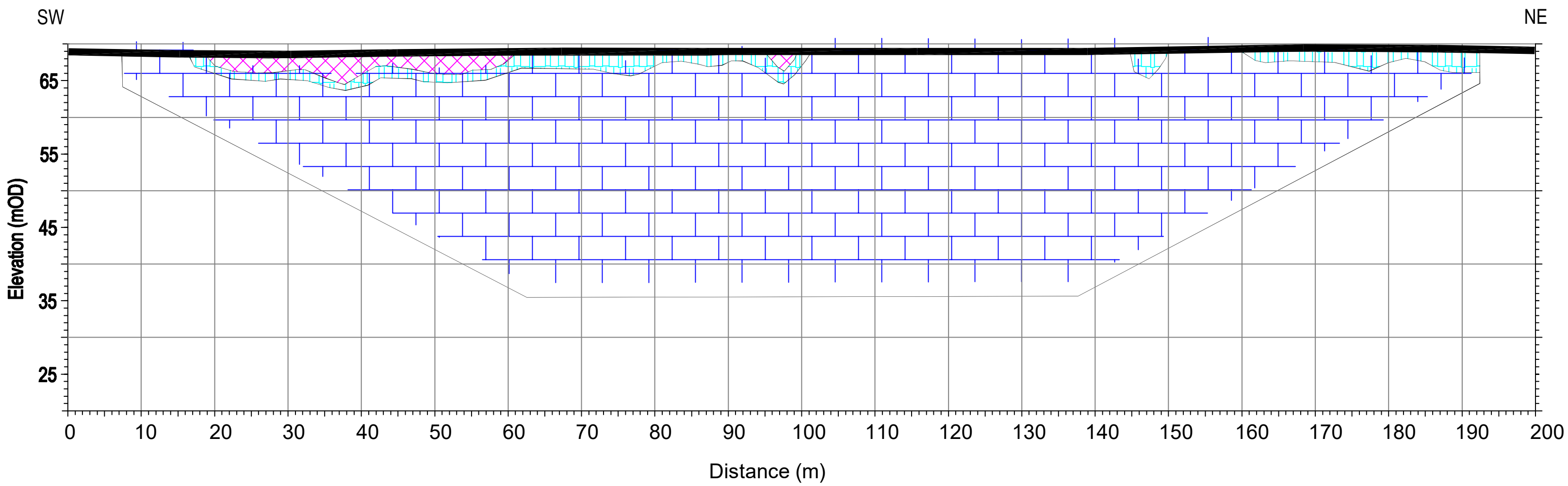
DRAWING NO:	AGP21195_R2
SCALE:	AS INDICATED @ A4
DATE:	07-02-2022

Version:	Date:	Drawn By:	Checked:
001	07-02-2022	POC	TL

RESISTIVITY PROFILE R3

SCALE 1:1000





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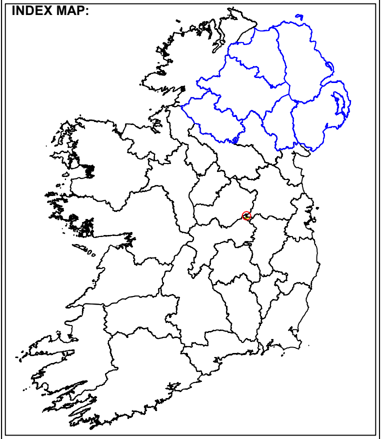

LEGEND:

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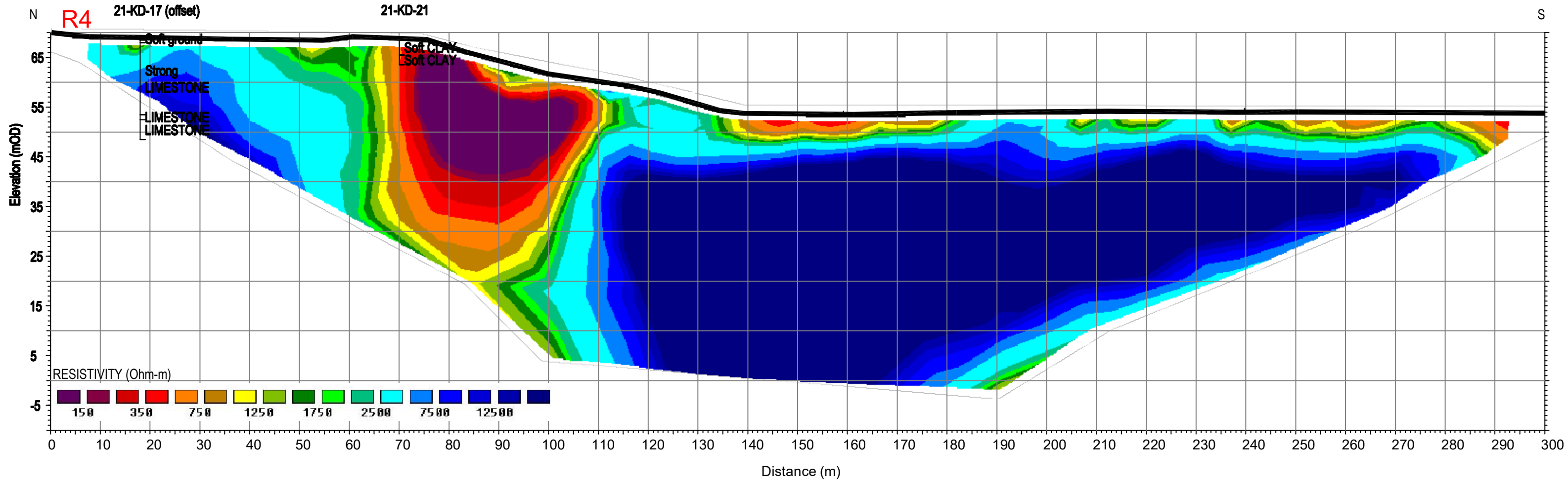
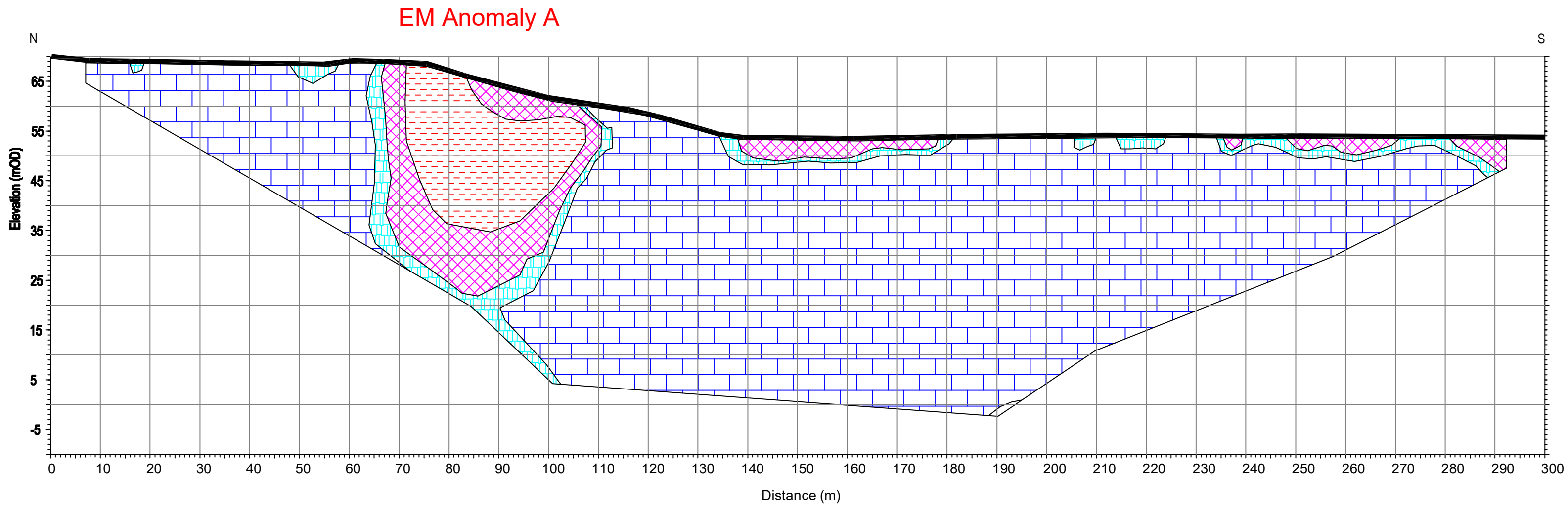
DRAWING NO:	AGP21195_R3
SCALE:	AS INDICATED @ A4
DATE:	07-02-2022

Version:	Date:	Drawn By:	Checked:
001	07-02-2022	POC	TL

RESISTIVITY PROFILE R4

SCALE 1:1500





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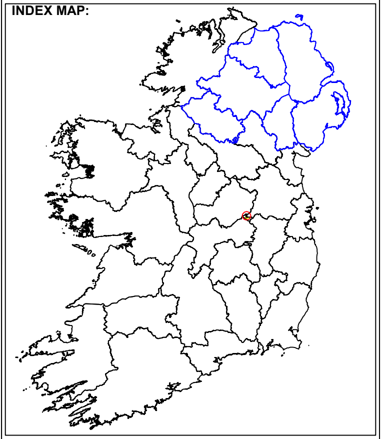

LEGEND:

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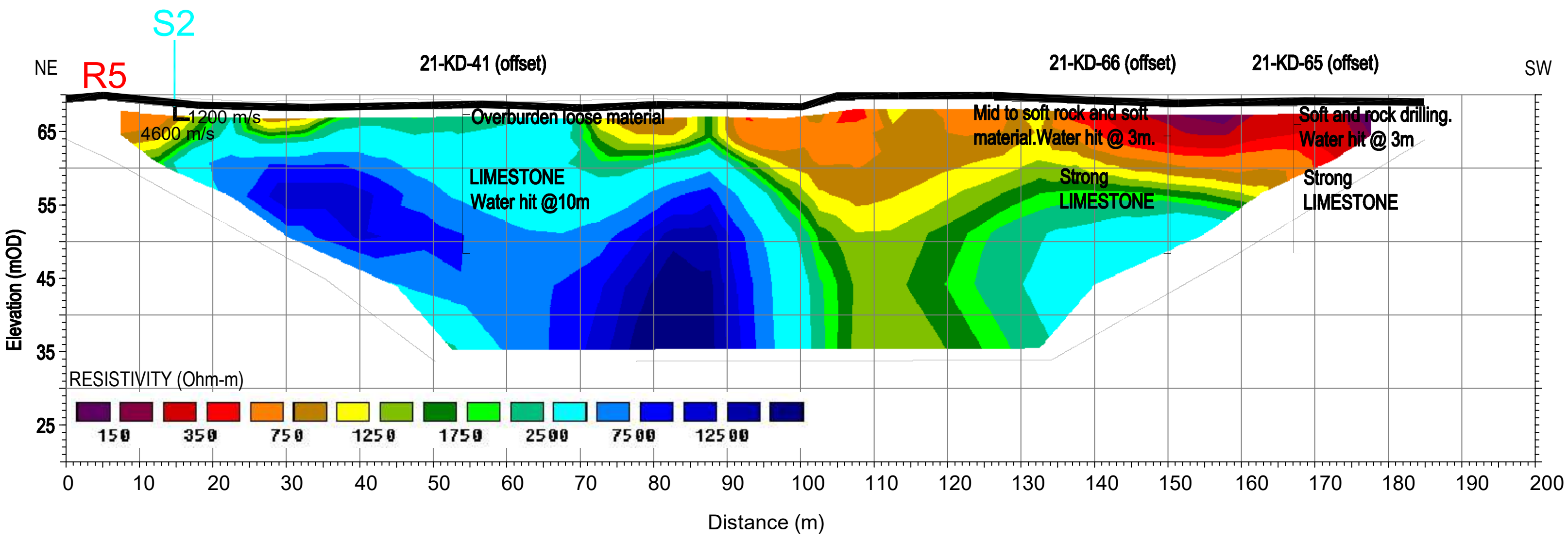
DRAWING NO:	AGP21195_R4
SCALE:	AS INDICATED @ A4
DATE:	07-02-2022

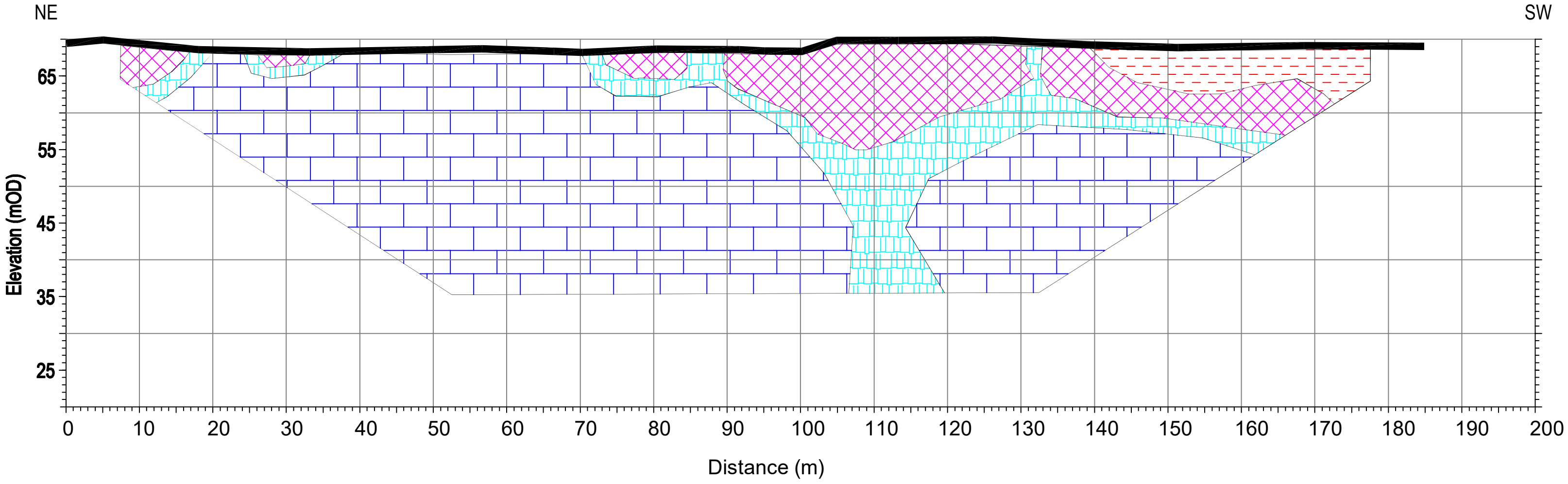
Version:	Date:	Drawn By:	Checked:
001	07-02-2022	POC	TL

RESISTIVITY PROFILE R5

SCALE 1:1000



EM Anomaly B



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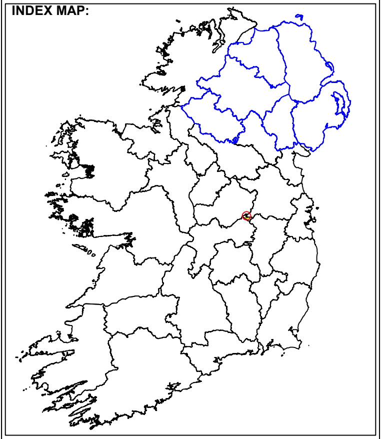

LEGEND:

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DRAWING NO:	AGP21195_R5
SCALE:	AS INDICATED @ A4
DATE:	07-02-2022

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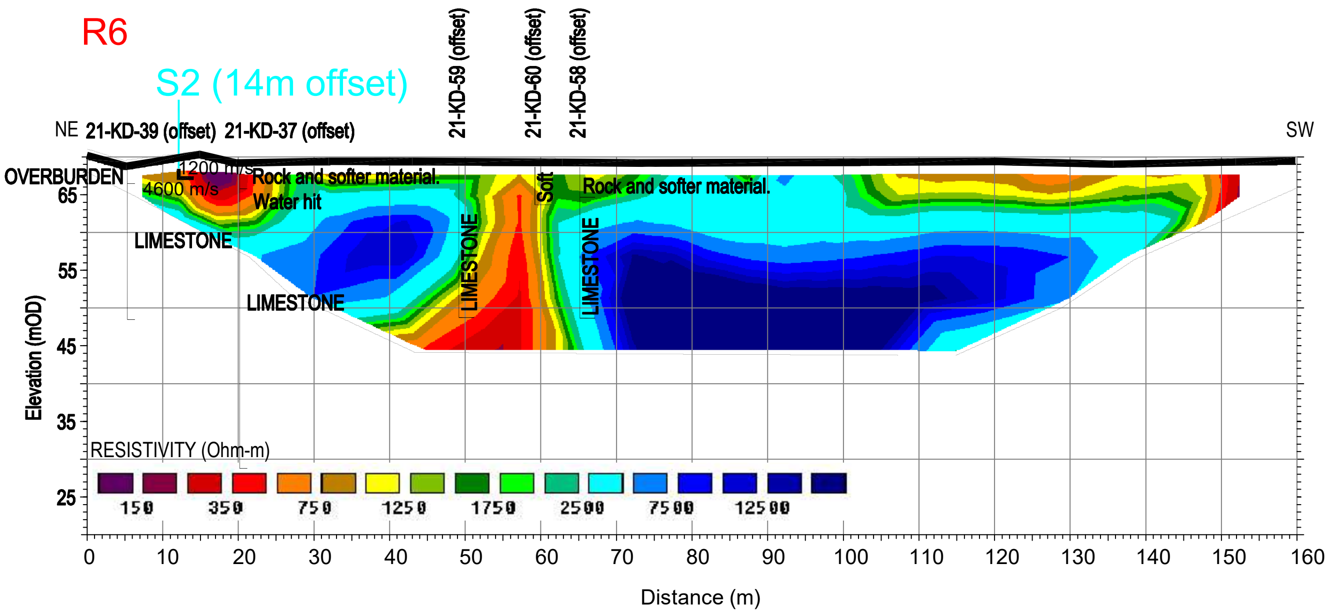
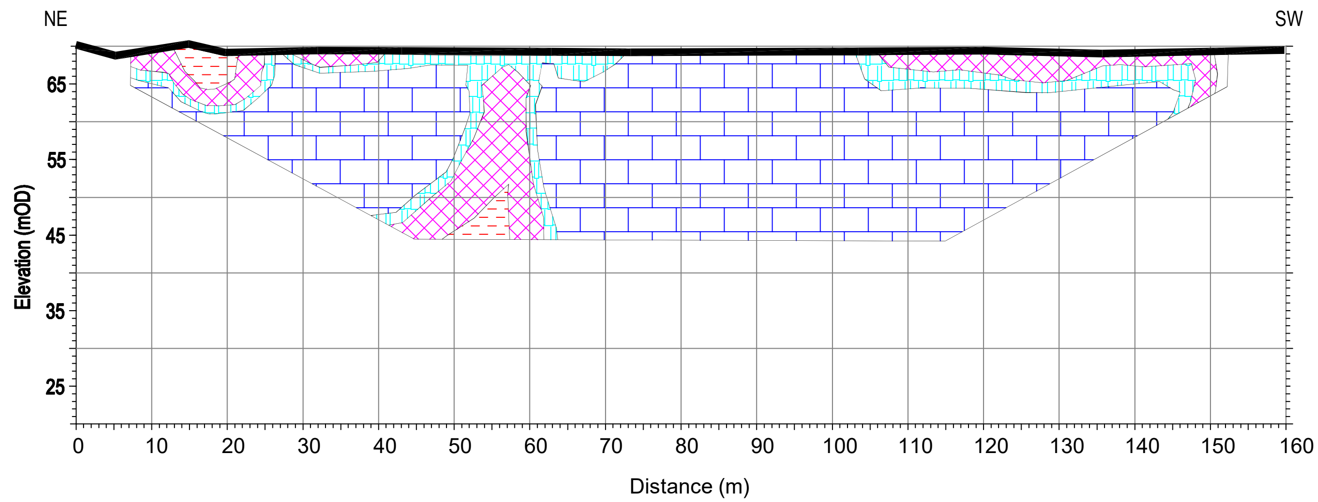
RESISTIVITY PROFILE R6

SCALE 1:1000



EM Anomaly B



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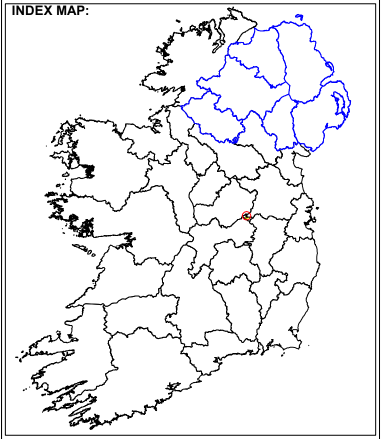

LEGEND:

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DRAWING NO:	AGP21195_R6
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DATE:	07-02-2022

Version:	Date:	Drawn By:	Checked:
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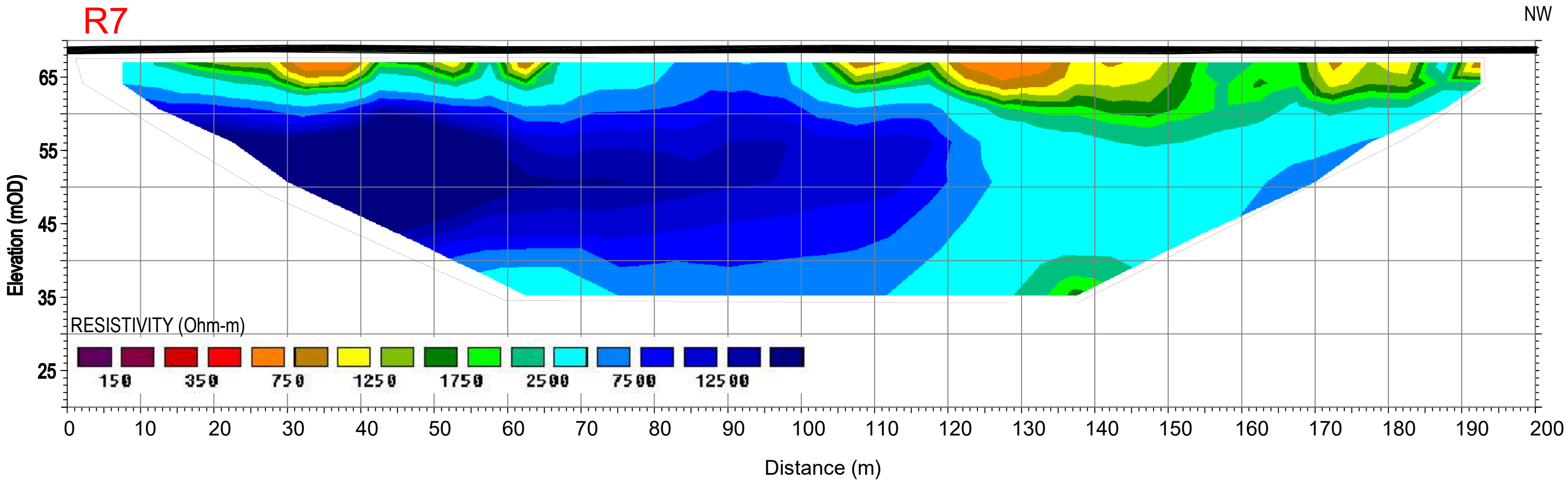
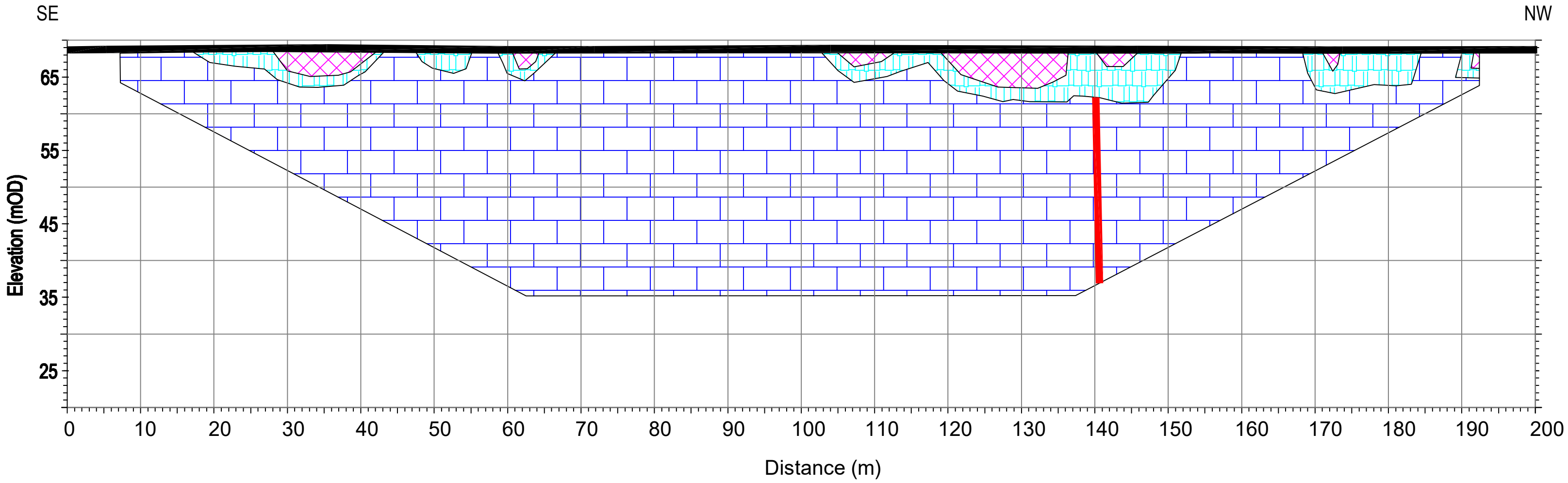
RESISTIVITY PROFILE R7

SCALE 1:1000





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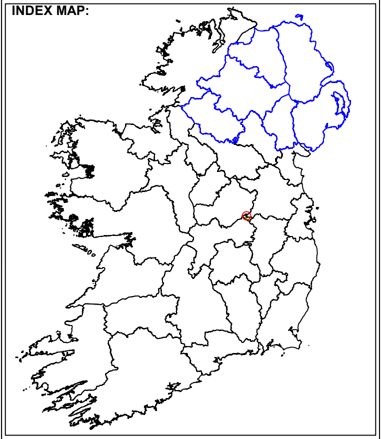

LEGEND:

OVERBURDEN - completely weathered LIMESTONE with clay infill

Highly weathered/ karstified/fractured LIMESTONE with clay infill

Mod, weathered/karstified/ fractured LIMESTONE with clay infill

Slightly weathered - fresh LIMESTONE

Possible Fault

21-KD-65 Borehole summary log

1400 m/s Seismic boundary and P-wave velocity

S1 Seismic Profile intersection

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Version:	Date:	Drawn By:	Checked:
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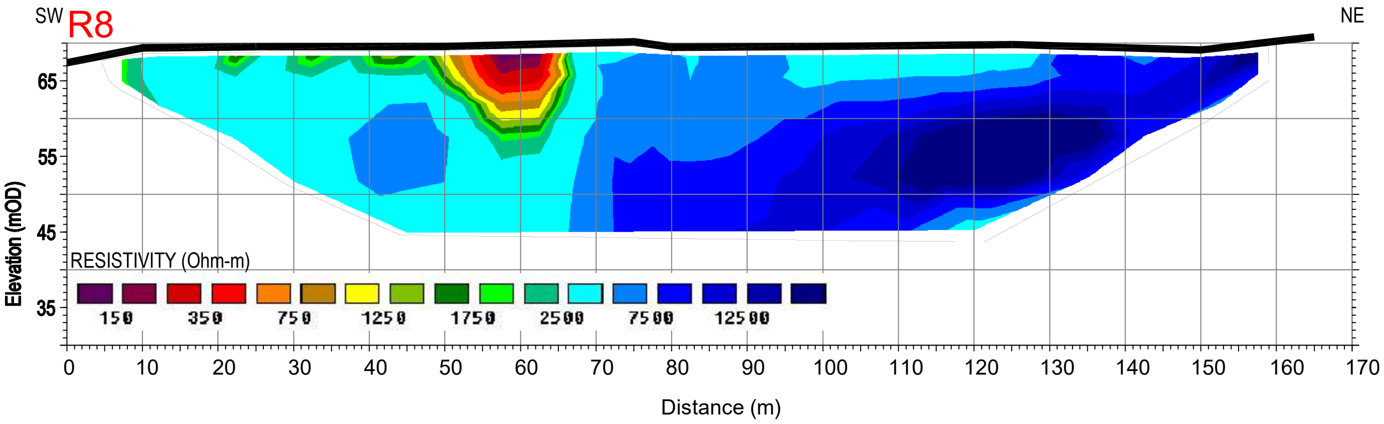
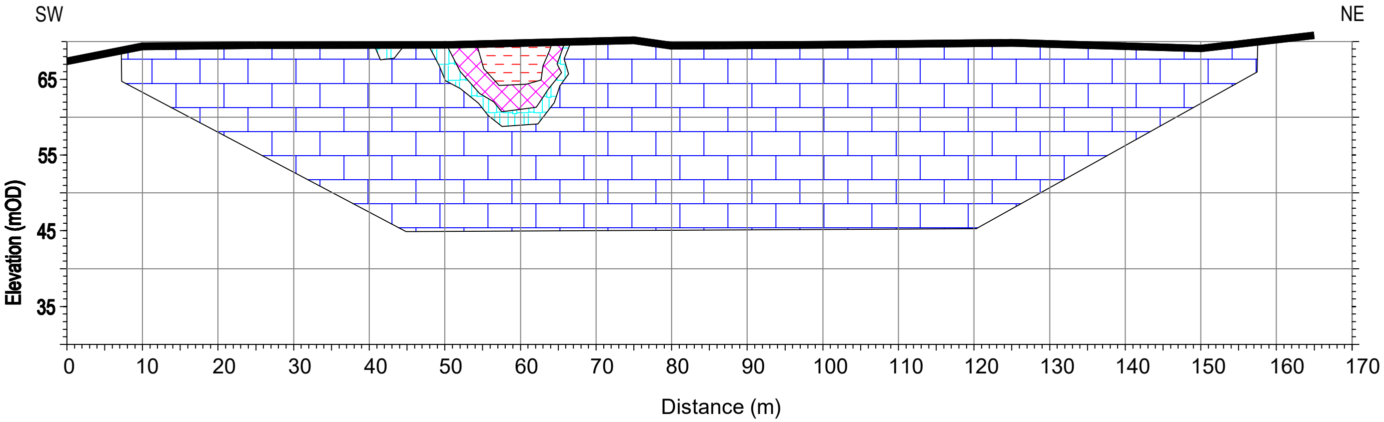
RESISTIVITY PROFILE R8

SCALE 1:1000





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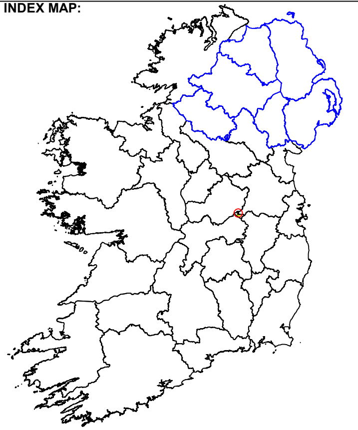

LEGEND:

OVERBURDEN - completely weathered LIMESTONE with clay infill

Highly weathered/ karstified/fractured LIMESTONE with clay infill

Mod, weathered/karstified/ fractured LIMESTONE with clay infill

Slightly weathered - fresh LIMESTONE

Possible Fault

21-KD-65 Borehole summary log

1400 m/s Seismic boundary and P-wave velocity

S1 Seismic Profile intersection

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Version:	Date:	Drawn By:	Checked:
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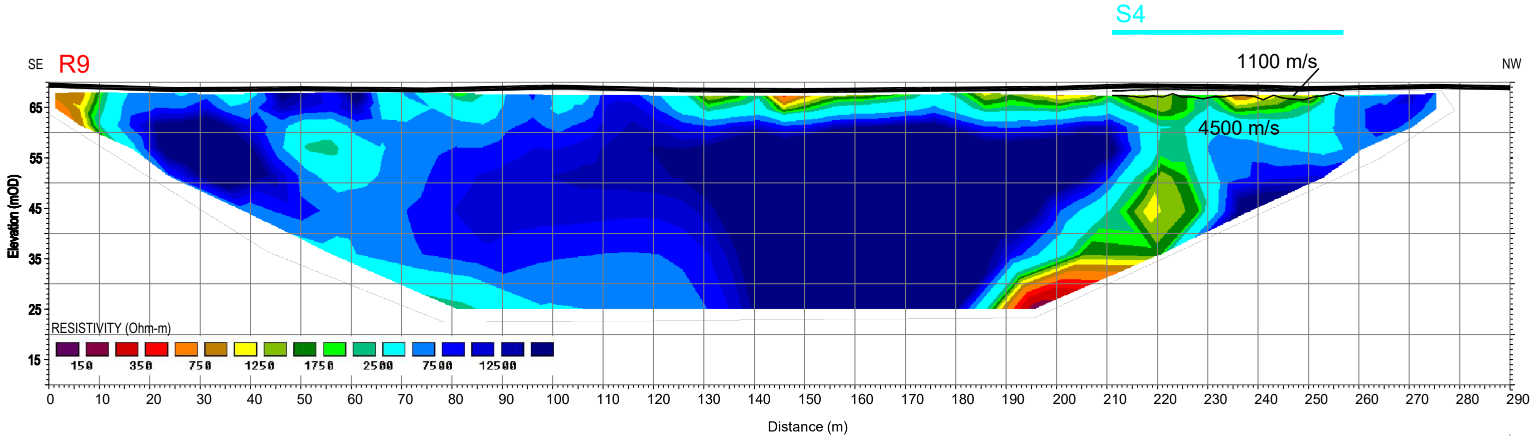
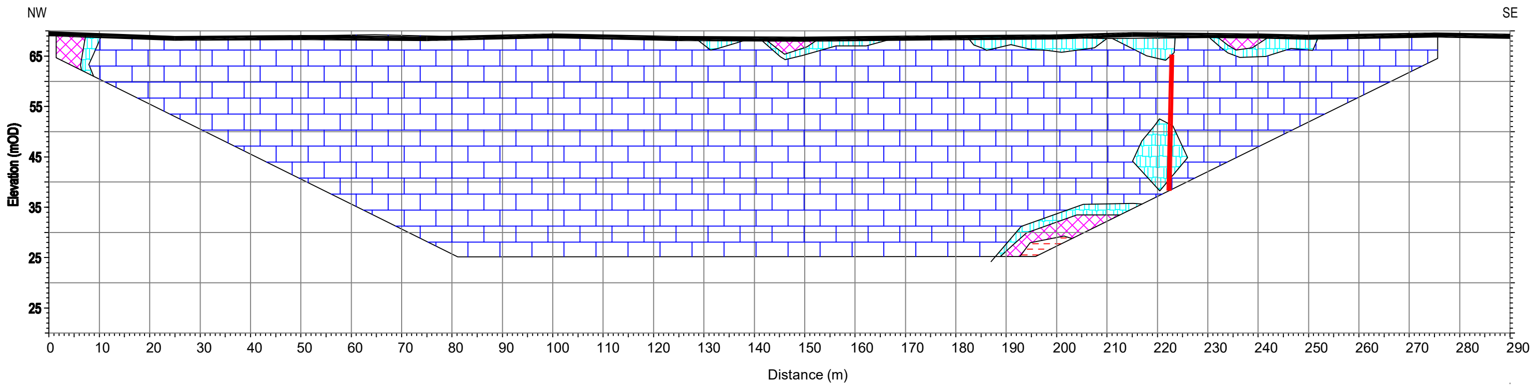
RESISTIVITY PROFILE R9 and SEISMIC PROFILE S4

SCALE 1:1500





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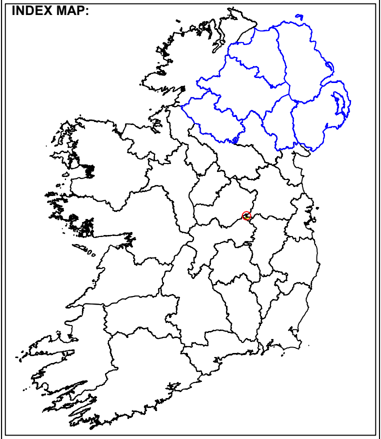

LEGEND:

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SCALE:	AS INDICATED @ A4
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Version:	Date:	Drawn By:	Checked:
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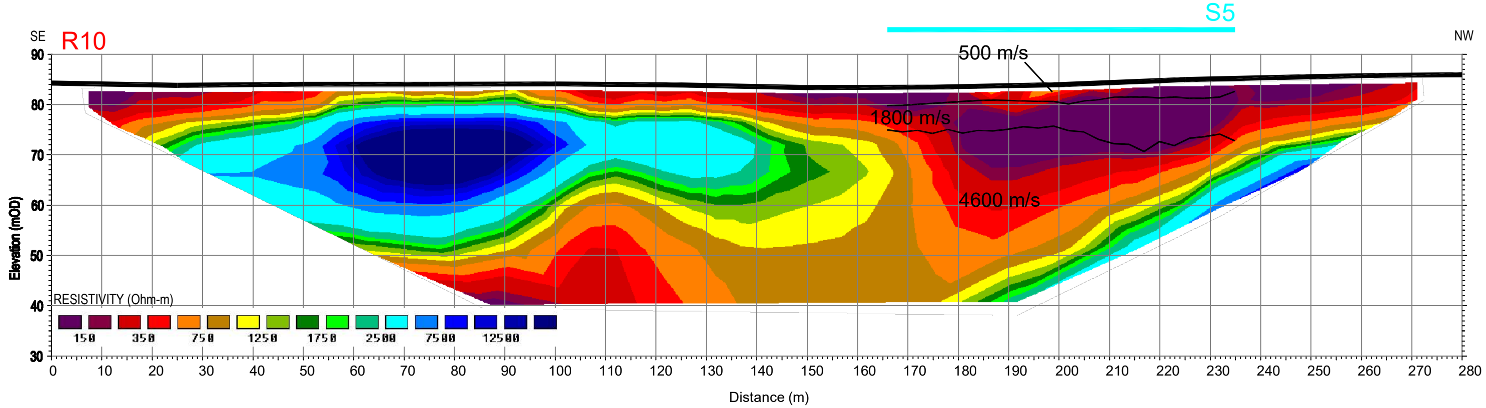
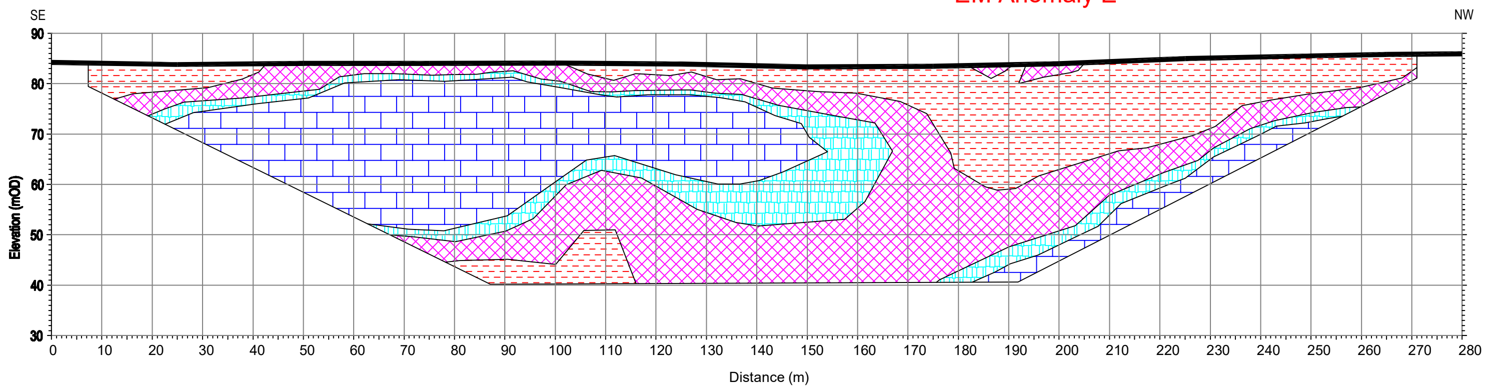
RESISTIVITY PROFILE R10 and SEISMIC PROFILE S5

SCALE 1:1500





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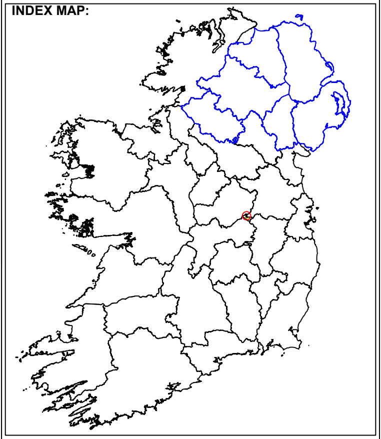

LEGEND:

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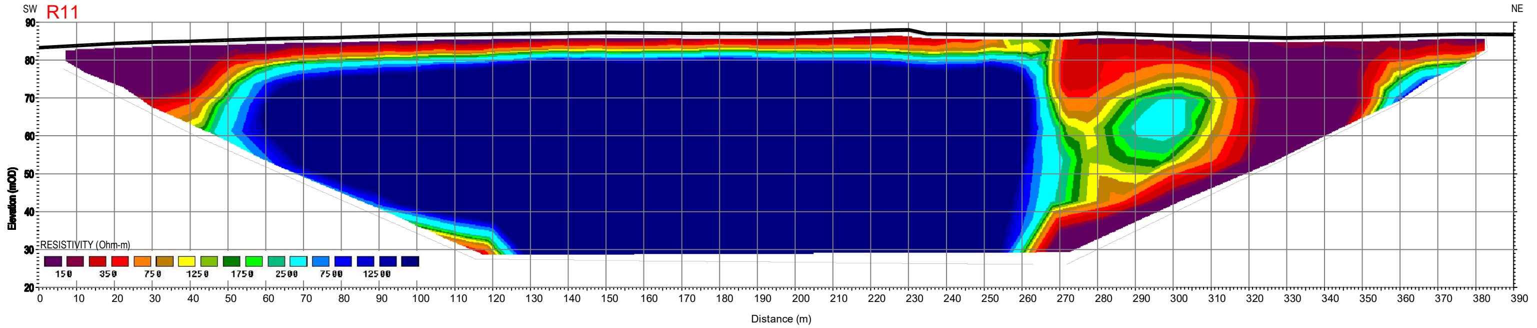
DRAWING NO:	AGP21195_R10
SCALE:	AS INDICATED @ A4
DATE:	07-02-2022

Version:	Date:	Drawn By:	Checked:
001	07-02-2022	POC	TL

RESISTIVITY PROFILE R11

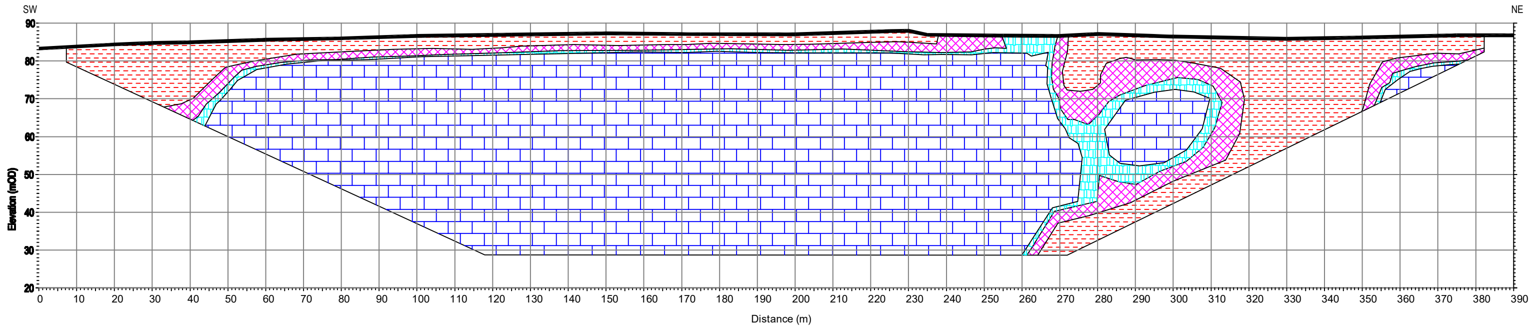
SCALE 1:2000



EM Anomaly E

EM Anomaly F

EM Anomaly G



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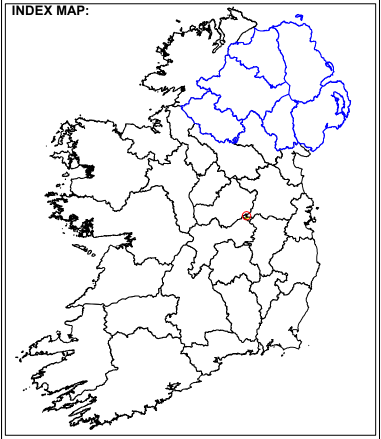

LEGEND:

- OVERBURDEN - completely weathered LIMESTONE with clay infill
- Highly weathered/ karstified/fractured LIMESTONE with clay infill
- Mod, weathered/karstified/ fractured LIMESTONE with clay infill
- Slightly weathered - fresh LIMESTONE
- Possible Fault
- 21-KD-65 Borehole summary log
- 1400 m/s Seismic boundary and P-wave velocity
- S1 Seismic Profile intersection

The information displayed here is to be used in conjunction with AGP21195_01 Report on a Geophysical Investigation at Kinnegad Quarry for THE BREEDON GROUP., APEX Geophysics Ltd. 7th February 2022.

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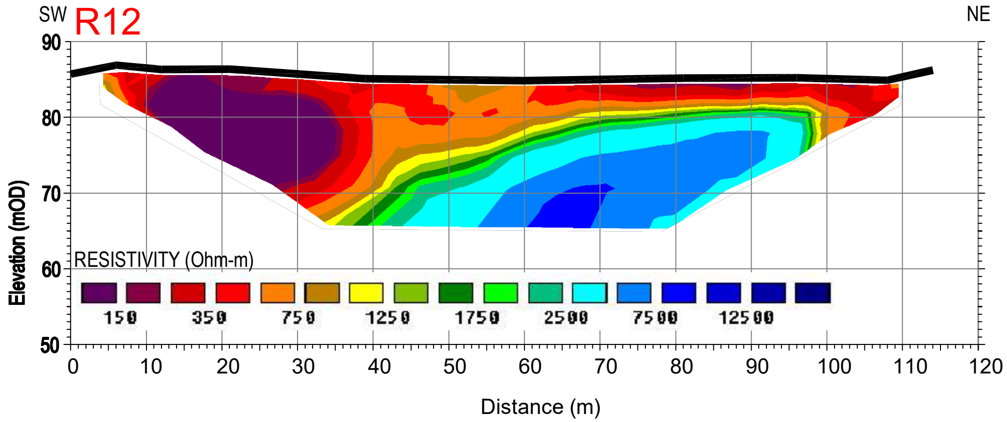
PROJECT:	KINNEGAD QUARRY GEOPHYSICAL SURVEY PHASE II
CLIENT.:	THE BREEDON GROUP
DRAWING NO:	AGP21195_R11
SCALE:	AS INDICATED @ A4
DATE:	07-02-2022

Version:	Date:	Drawn By:	Checked:
001	07-02-2022	POC	TL

RESISTIVITY PROFILE R12

SCALE 1:1000



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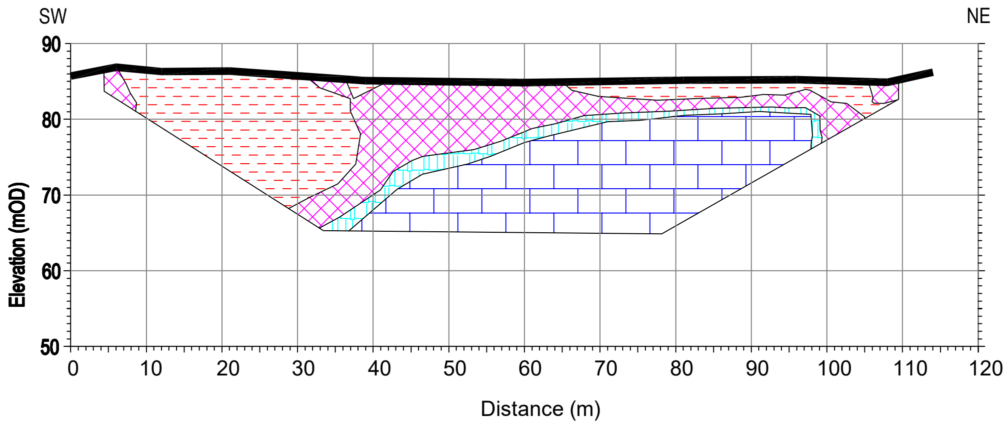

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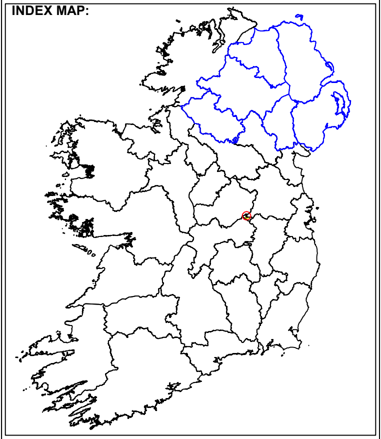

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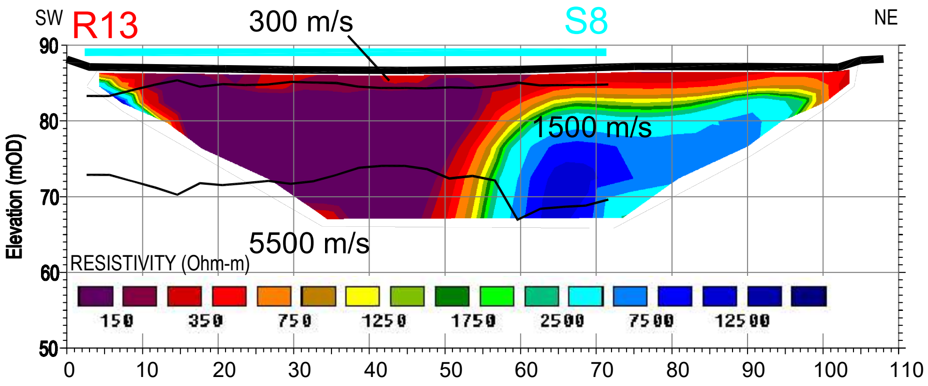
RESISTIVITY PROFILE R13 and SEISMIC PROFILE S8

SCALE 1:1000



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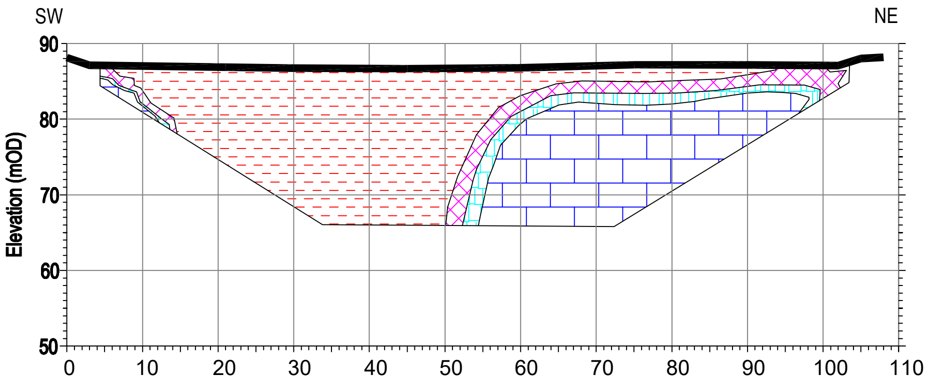

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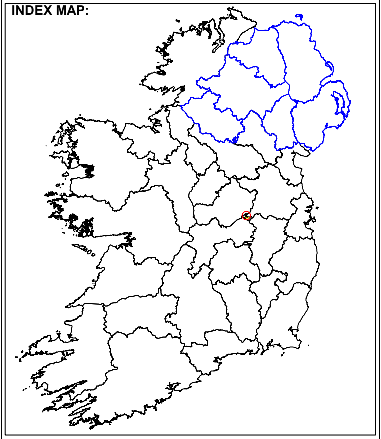

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Version:	Date:	Drawn By:	Checked:
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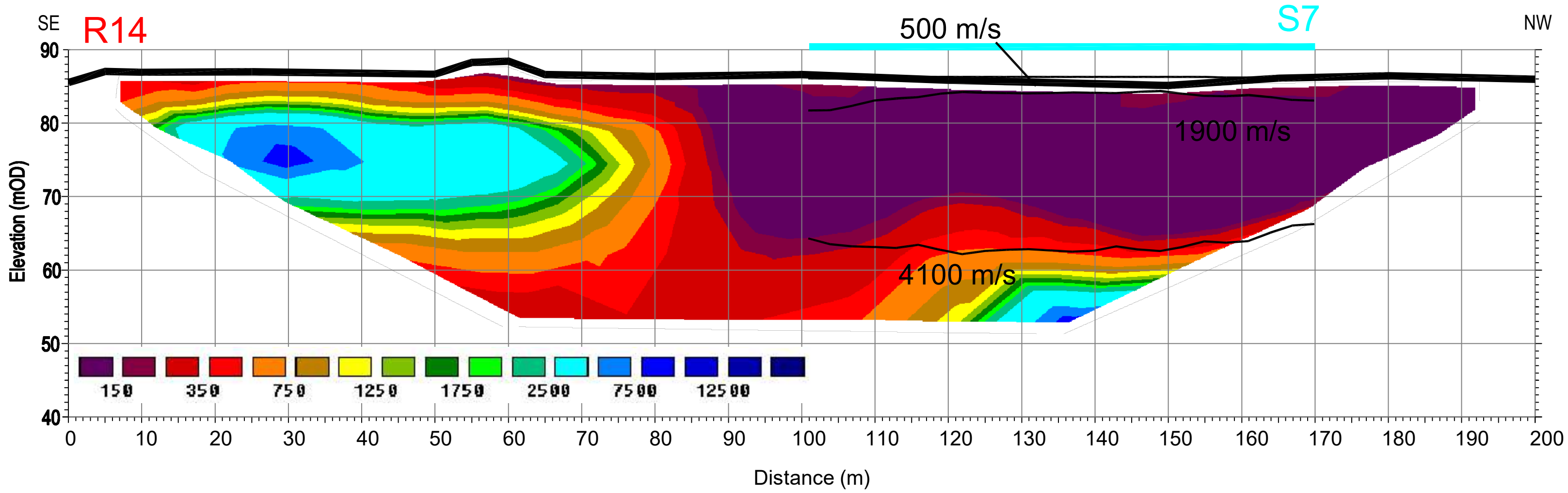
RESISTIVITY PROFILE R14 and SEISMIC PROFILE S7

SCALE 1:1000



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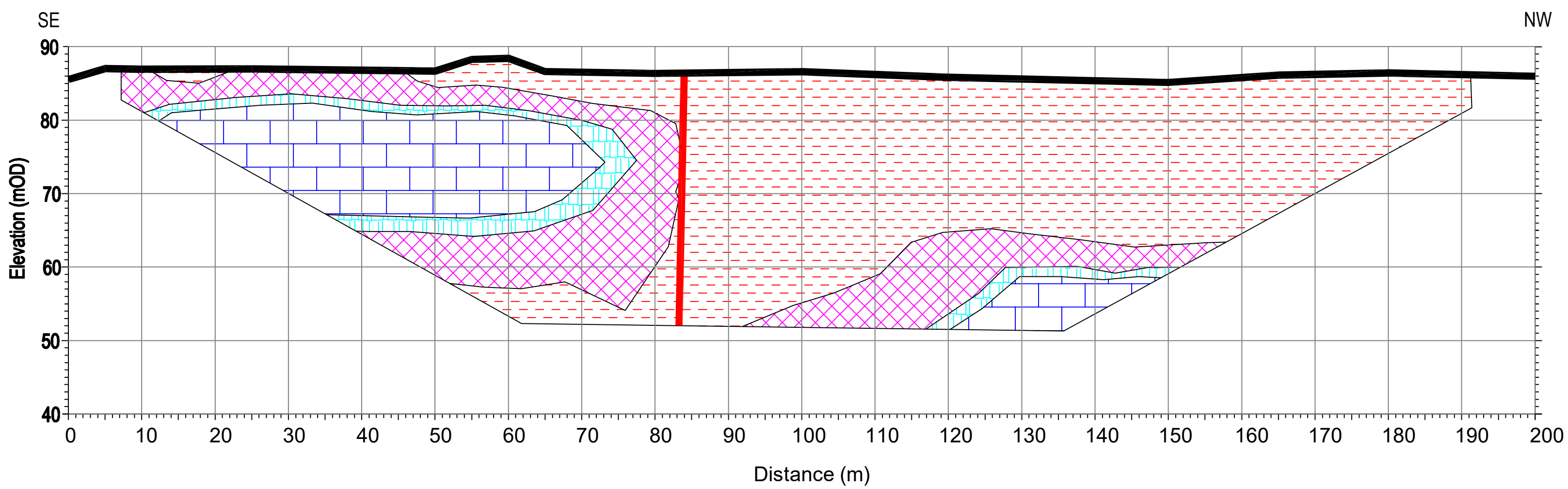
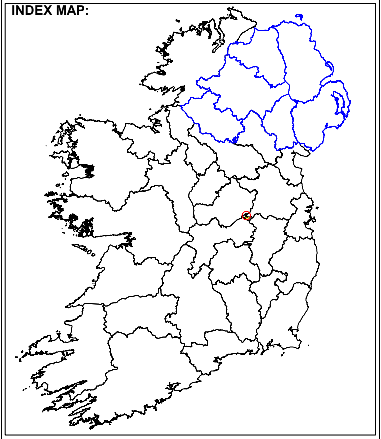


INDEX MAP:



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DRAWING NO:	AGP21195_R14
SCALE:	AS INDICATED @ A4
DATE:	07-02-2022

Version:	Date:	Drawn By:	Checked:
001	07-02-2022	POC	TL

APPENDIX B: DETAILED GEOPHYSICAL METHODOLOGY

A combination of geophysical techniques was used to provide a high quality interpretation and reduce any ambiguities, which may otherwise exist.

EM Ground Conductivity Mapping

Principles

This is an electromagnetic technique used to investigate lateral variations in overburden material and to assist with the indication of the depth to bedrock. This method operates on the principle of inducing currents in conductive substrata and measuring the resultant secondary electro-magnetic field. The strength of this secondary EM field is calibrated to give apparent ground conductivity in milliSiemens/metre (mS/m). Readings over material such as organic waste and peat give high conductivity values while readings over dry materials with low clay mineral content such as gravels, limestone or quartzite give low readings. The EM31 survey technique determines the apparent conductivity of the different overburden layers from 0-6m bgl depending on the dipole mode used.

Data collection

The EM31 equipment used was a GF CMD-4 conductivity meter equipped with data logger. This instrument features a real time graphic display of the previous 20 measurement points to monitor data quality and results. Conductivity and in-phase values were recorded across the site. Local conditions and variations were recorded.

Data processing

The conductivity and in-phase field readings were downloaded, contoured and plotted using the SURFER 12 program (Golden Software, 2015). Data which was affected by metallic objects was removed. Assignation of material types and possible anomaly sources was carried out, with cross-reference to other data.

Electrical Resistivity Tomography (ERT)

Electrical Resistivity Tomography was carried out to provide information on lateral variations in the overburden material as well as on the underlying overburden and bedrock.

Principles

This surveying technique makes use of the Wenner resistivity array. The 2D-resistivity profiling method records a large number of resistivity readings in order to map lateral and vertical changes in material types. This method involves the use of electrodes connected to a resistivity meter, using computer software to control the process of data collection and storage.

Data Collection

Profiles were recorded using an ABEM LS4 resistivity meter, imaging software, four 21 takeout multicore cables and up to 80 stainless steel electrodes. Saline solution was used at the electrode/ground interface in order to gain a good electrical contact required for the technique to work effectively. The recorded data were processed and viewed immediately after surveying.

Data Processing
The field readings were stored in computer files and inverted using the RES2DINV package (Geotomo Software, 2006) with up to 5 iterations of the measured data carried out for each profile to obtain a 2D-depth model of the resistivities.

The inverted 2D resistivity models and corresponding interpreted geology are displayed on the accompanying drawings alongside the processed seismic sections. Profiles have been contoured using the same contour intervals and colour codes. Distance is indicated along the horizontal axis of the profiles.

Seismic Refraction Profiling

Principles
This method measures the velocity of refracted seismic waves through the overburden and rock material and allows an assessment of the thickness and quality of the materials present to be made. Stiffer and stronger materials usually have higher seismic velocities while soft, loose or fractured materials have lower velocities.

Seismic profiling measures the p-wave velocity (Vp) of refracted seismic waves through the overburden and rock material and allows an assessment of the thickness and quality of the materials present to be made. Stiffer and stronger materials usually have higher Vp velocities while soft, loose or fractured materials have lower Vp velocities. Readings are taken using geophones connected via multi-core cable to a seismograph.

Data Collection
A Geode high resolution 24 channel digital seismograph, 24 10HZ vertical geophones and a 10 kg hammer were used to provide first break information, with a 24 take-out cable. Equipment was carried and operated by a two-person crew.

Readings are taken using geophones connected via multi-core cable to a seismograph. The depth of resolution of soil/bedrock boundaries is determined by the length of the seismic spread, typically the depth of resolution is about one third the length of the profile.(eg. 69m profile ~23m depth, 33m profile ~ 11m depth).

Data Processing
First break picking in digital format was carried out using the FIRSTPIX software program to construct p-wave (Vp) traveltime plots for each spread. Velocity phases were selected from these plots using the GREMIX software program and were used to calculate the thickness of individual velocity units. Topographic data were input. Material types were assigned and estimation made of material properties. The processed seismic data are displayed in Appendix C.

GREMIX interprets seismic refraction data as a laterally varying layered earth structure. It incorporates the slope-intercept method, parts of the Plus-Minus Method of Hagedoorn (1959), Time-Delay Method, and features the Generalized Reciprocal Method (GRM) of Palmer (1980). Up to four layers can be mapped; one deduced from direct arrivals and three deduced from refractions. Phantoming of all possible travel time pairs can be carried

Approximate errors for Vp velocities are estimated to be +/- 10%. Errors for the calculated layer thicknesses are of the order of +/-20%. Possible errors due to the "hidden layer" and "velocity inversion" effects may also occur (Soske, 1959).

Spatial Relocation

All the geophysical investigation locations were acquired using a Trimble Geo 7X high-accuracy GNSS handheld system using the settings listed below.

Projection:	Irish Transverse Mercator
Datum:	Ordnance
Coordinate units:	Metres
Altitude units:	Metres
Survey altitude reference:	MSL
Geoid model:	Republic of Ireland

APPENDIX D: EXTRACT FROM OPEN HOLE DRILLING SUMMARY MAP BY SLR