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Department of Communications, Climate Action & Environment

Geological Survey
Suirbhéireacht Gheolaíochta
Ireland | Éireann

Research Programme
- Short Calls, Final Report -

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Host Organisation name	University College Dublin
Project Title	Distribution and Engineering Properties of Interglacial Deposits in Cork City and harbour
Contract Number	2017-sc-009

Date: 02/11/18

This report covers the period November 1st 2017 to September 30th 2018

2.0 Project Information

2.1 Project Objectives

The primary objectives of this project are to develop an understanding of the engineering parameters of Gortian interglacial deposits found within the Cork City gravels. Past site investigation reports were examined to identify the distribution of these deposits. In tandem, a rockhead topographic map of the study area was developed to examine the potential link between rockhead and the interglacial deposits. The project involved a complete reassessment of the existing borehole records and any associated testing data in the Geological Survey of Ireland's (GSI) online and in-house database and making use of additional data available from ARUP, University College Dublin (UCD), engineering consultancies and site investigation contractors.

In addition to the historical drilling data, several electrical resistivity tomography (ERT) surveys were carried out, with the aid of the GSI, to assess the effectiveness of resistivity measurements to distinguish between the fluvio-glacial gravels and the stiff silty clays. Several samples were obtained from Professor Pete Coxon of Trinity College Dublin(TCD), originally excavated as part of a palynological investigation of the Gortian deposits. Extensive testing was carried out on these samples to investigate the composition and engineering parameters of this material.

The overall objectives for the project were as follows:

- Define a study area that would provide sufficient information representative of the Quaternary geological history of the area.
- Collect and collate all relevant data from the GSI, UCD and relevant engineering bodies.
- Review logs and geotechnical lab testing to identify the presence of interglacial deposits.
- Learning and use of GIS software and data management program gINT
- Define the location, distribution and lateral extent of interglacial deposits.
- In parallel to the interglacial deposits, develop a map of the top of bedrock in the study area.
- Compare any variation within the deposits by comparing a number of major SI projects encountering the Gortian clays.
- Extensive laboratory work on samples sourced from Prof. Pete Coxon of TCD (Atterberg limits, particle size distribution, loss on ignition, specific gravity and oedometer testing)
- Analysis of lab testing and assessment using "Burlands – Intrinsic Properties framework" to aid in the investigation of the materials sedimentary and compressional history.
- Carry out and process ERT testing using GSI equipment – 2 visits.

To date, very little research exists on the engineering properties of the stiff interglacial clays in Cork City. No study exists which examines the true extent and distribution of this stiff clay deposit. Past publications on these Gortian interglacial deposits have been focused on a small number of locations, in particular at Custom House Quay (CHQ). These studies primarily examine the palynology and ageing of the material and the ongoing debate as to the true location of the Gortian within the stratigraphic column. The only publication to discuss the engineering properties of the clays is Farrell (2016). In this study results from the 1979 Site Investigation Ltd. CHQ report are referenced in relation to the engineering parameters of Irish interglacial deposits.

Site investigations for the southern Custom House Bridge (now known as the Eamonn de Valera Bridge) in the late 1970s made the surprising discovery of a stiff over consolidated clay below the usual Cork glacio-fluvial gravels, as seen in Figure 1. Professor Robert Devoy of UCC recognised these deposits as belonging to the Pleistocene interglacial (probably Gortian), see Devoy (1983, 1984). These were composed of 16.5m of laminated and organic-rich green grey silty clays, lying beneath 18m of highly consolidated gravels, estuarine silts and made ground.

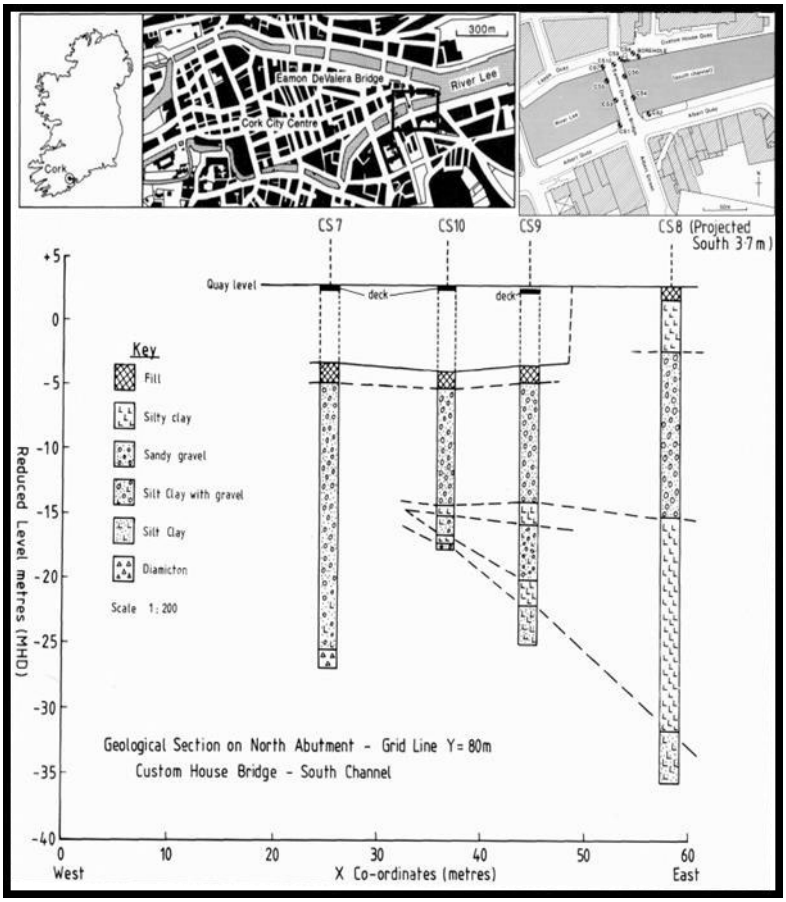


Figure 1: Cross Section from 1979 Site investigation at CHQ. (Scourse et al. (1992))

Since this first discovery, the interglacial deposits have been re-investigated by (Scourse *et al.*, 1992) and (Dowling, 1997) excavating boreholes through the clay at CHQ and additionally in Carrigtoohill and Douglas.

Discrepancies still exist in the geological setting of the Gortian group of deposits. Though it is largely recognised that these are interglacial deposits, opinions remain split between the Gortian interglacial period being Ireland's final interglacial (W.P.Warren, 1979) or Ireland's penultimate interglacial (Devoy(1983, 1984), Mitchell, 1970; Dowling, 1997; Coxon, 2001, Watts (1985)

The GSI has created a 3-D geological model of the greater Cork City region which is available from their online database. This model provides a great key for the display of a larger scale overview of Cork's bedrock levels and Quaternary sediments. The large scale of this model and localised, sporadic distribution of interglacial deposits does however render imaging the clays impossible.

The data gathered for this project is believed to have extended the depth of current understanding of these deposits. This study combines the information gathered as part of these palynological studies and localised site investigation reports to create a more regional understanding of these interglacial deposits. This study develops an understanding of the compositional and engineering characteristics of these interglacial clays and will prove a useful tool for future construction and infrastructure projects in the city.

2.2 Implementation

For timescale purposes, the project was divided into 7 approximate stages outlined in Table 1. Each stage was allocated a deadline, allowing for the best usage of time. A number of stages overlapped due to equipment, site access and lab availability. Each stage was assigned a proposed amount of time, deadlines were set and the completion of each stage marked a milestone. Upon completion of each stage, progress meetings were organised with the work critiqued, suggestions made and details and timelines for future stages updated following the meetings.

It is important to note that, at the time of writing (October 2018), this study is still ongoing and is due for completion in January 2019, upon which time a MEngSC thesis will be made available to the GSI.

The 7 stages were comprised of:

	Task	Time Allocated (months)
1	Definition of Study Area	0.5
2	Source and assessment of borehole and test data	3
3	Learning of GIS, gINT etc. Input of data and the development of geospatial datasets etc.	1.5
4	ERT surveys - Scouting, fieldwork, processing (2 visits)	1.5
5	Laboratory work, including sourcing of samples, learning test methods, calibration of equipment, carrying out and analysis of all testing	3
6	Report and Poster for GSI	0.5
7	Production of MEngSC Thesis	2

Table 1: Implementation stages

1.2.1 Definition of Study

At the very earliest stages of the study it was important to define the direction of the study. Past literature was examined and a review undertaken of the available relevant borehole data sourced from the archives of the GSI, data available at UCD and reports from numerous engineering bodies, such as ARUP. Following discussion with Mike Long (UCD), Marie Fleming (ARUP), Beatriz Mozo (GSI) and Mike Sheehy (GSI), the study area, seen in Figure 2, was chosen. The area is located predominantly to the east of Cork City centre. The study area chosen is approx. 13 km^2 in area and extends from Merchants Quay to the Jack Lynch Tunnel, bound to the north by the Lower Glanmire Road and Blackrock Road to the south. As an area with strong plans for future development, it contains the most records of these interglacial deposits and a complex variation in rockhead elevation.

Figure 2: Extents of the study area

2.2.2 Assessment of borehole and test data.

Past site investigation reports have formed the basis of the bulk of this study. Borehole and lab data were sourced predominantly from the GSI, both from their online database (Geotechnical Data Viewer, Goldmine) and from their in-house archives in Beggars Bush. Material was also sourced in UCD from previous projects. Geological/ SI reports were made available by engineering bodies such as ARUP and Carraigex, although this was often limited due to privacy/ownership issues.

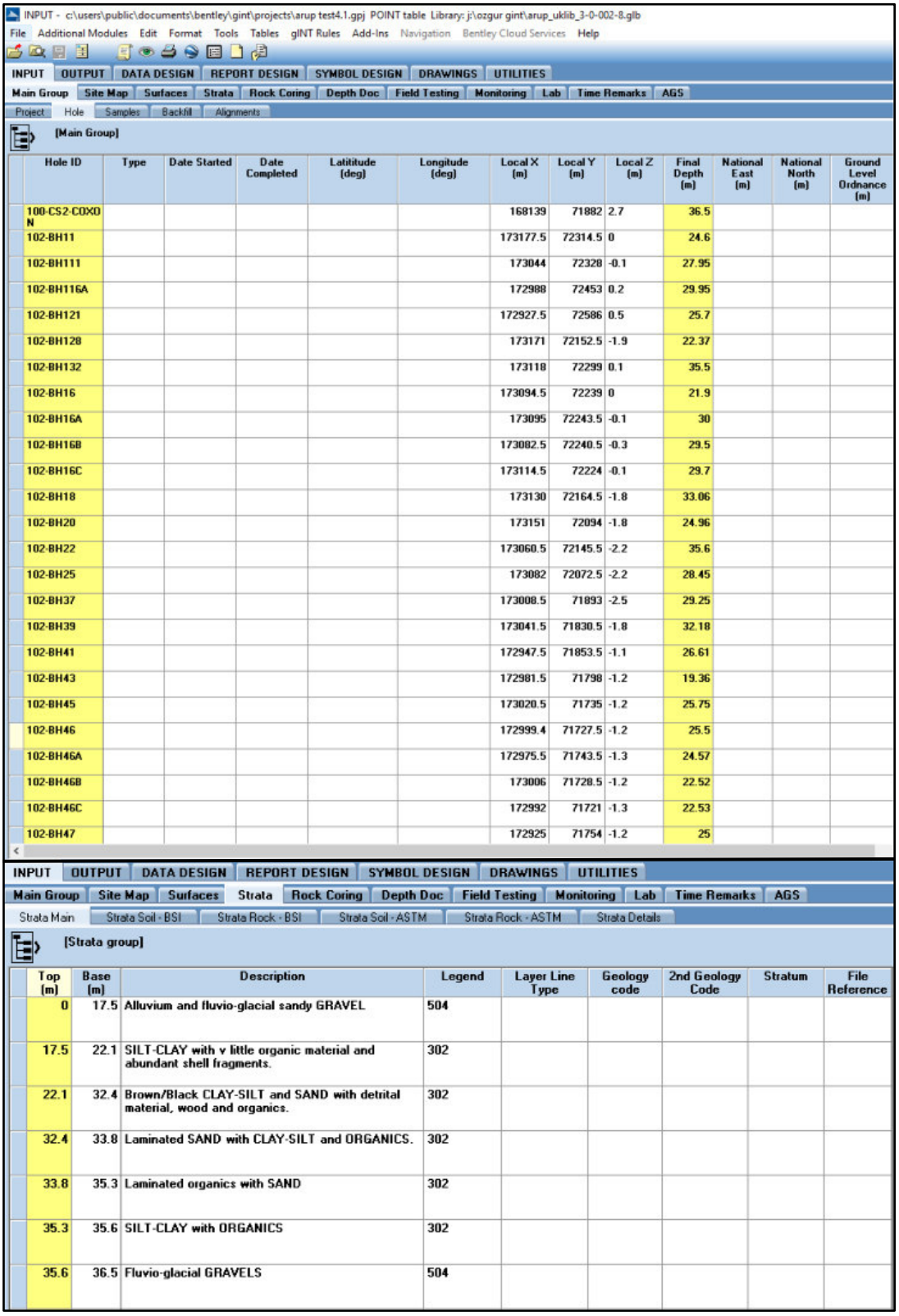
Logs from the available reports were all reassessed and potential interglacial strata highlighted based on their descriptions, stratigraphical position and the available lab and in-situ testing.

Outdated drilling methods, such as pneumatic and wagon drilling, and poor material descriptions were common, particularly in reports prior to the 1970s. Reports often contained potential interglacial material described as “Mud” or even “Dirt”. In instances such as these, stratigraphical correlation to a nearby, more reliable borehole was necessary. Otherwise, such suspected interglacial materials had to be omitted from the study. Similarly, for the definition of rockhead, the assumption was made that the greater penetration of rockhead, the more reliable the bedrock level. In cases of cable percussion borehole refusal, if over an hours chiselling was noted the rockhead level was compared to a nearby more reliable borehole. Where rockhead elevation shows a discrepancy greater than 1.5m, the rockhead level was omitted but the overburden data still used.

2.2.3 Data Input and correlation

The data collected from past site investigation reports was input to several Excel spreadsheets. These spreadsheets contain strata elevations, thicknesses and the available in-situ and lab test results with location co-ordinated in the Irish Grid system. The spreadsheet data was later used in ArcGIS to aid visualise the data.

Geotechnical information was input to gINT geotechnical software, forming a master database for all borehole data. No data in the study area existed in the AGS format, so all drilling logs and test results required manual input into the software. gINT proved a very useful tool for the development of logs, cross section and graphical representation of test data as seen in Figures 3 and 4.



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INPUT OUTPUT DATA DESIGN REPORT DESIGN SYMBOL DESIGN DRAWINGS UTILITIES

Main Group Site Map Surfaces Strata Rock Coring Depth Doc Field Testing Monitoring Lab Time Remarks AGS

Project Hole Samples Backfill Alignments

[Main Group]

Hole ID	Type	Date Started	Date Completed	Latititude (deg)	Longitude (deg)	Local X (m)	Local Y (m)	Local Z (m)	Final Depth (m)	National East (m)	National North (m)	Ground Level Ordnance (m)
100-CS2-COXDN						168139	71882	2.7	36.5			
102-BH11						173177.5	72314.5	0	24.6			
102-BH111						173044	72328	-0.1	27.95			
102-BH116A						172988	72453	0.2	29.95			
102-BH121						172927.5	72586	0.5	25.7			
102-BH128						173171	72152.5	-1.9	22.37			
102-BH132						173118	72299	0.1	35.5			
102-BH16						173094.5	72239	0	21.9			
102-BH16A						173095	72243.5	-0.1	30			
102-BH16B						173082.5	72240.5	-0.3	29.5			
102-BH16C						173114.5	72224	-0.1	29.7			
102-BH18						173130	72164.5	-1.8	33.06			
102-BH20						173151	72094	-1.8	24.96			
102-BH22						173060.5	72145.5	-2.2	35.6			
102-BH25						173082	72072.5	-2.2	28.45			
102-BH37						173008.5	71893	-2.5	29.25			
102-BH39						173041.5	71830.5	-1.8	32.18			
102-BH41						172947.5	71853.5	-1.1	26.61			
102-BH43						172981.5	71798	-1.2	19.36			
102-BH45						173020.5	71735	-1.2	25.75			
102-BH46						172999.4	71727.5	-1.2	25.5			
102-BH46A						172975.5	71743.5	-1.3	24.57			
102-BH46B						173006	71728.5	-1.2	22.52			
102-BH46C						172992	71721	-1.3	22.53			
102-BH47						172925	71754	-1.2	25			

INPUT OUTPUT DATA DESIGN REPORT DESIGN SYMBOL DESIGN DRAWINGS UTILITIES

Main Group Site Map Surfaces Strata Rock Coring Depth Doc Field Testing Monitoring Lab Time Remarks AGS

Strata Main Strata Soil - BSI Strata Rock - BSI Strata Soil - ASTM Strata Rock - ASTM Strata Details

[Strata group]

Top (m)	Base (m)	Description	Legend	Layer Line Type	Geology code	2nd Geology Code	Stratum	File Reference
0	17.5	Alluvium and fluvio-glacial sandy GRAVEL	504					
17.5	22.1	SILT-CLAY with v little organic material and abundant shell fragments.	302					
22.1	32.4	Brown/Black CLAY-SILT and SAND with detrital material, wood and organics.	302					
32.4	33.8	Laminated SAND with CLAY-SILT and ORGANICS.	302					
33.8	35.3	Laminated organics with SAND	302					
35.3	35.6	SILT-CLAY with ORGANICS	302					
35.6	36.5	Fluvio-glacial GRAVELS	504					

Figure 3: gINT logging software borehole interface

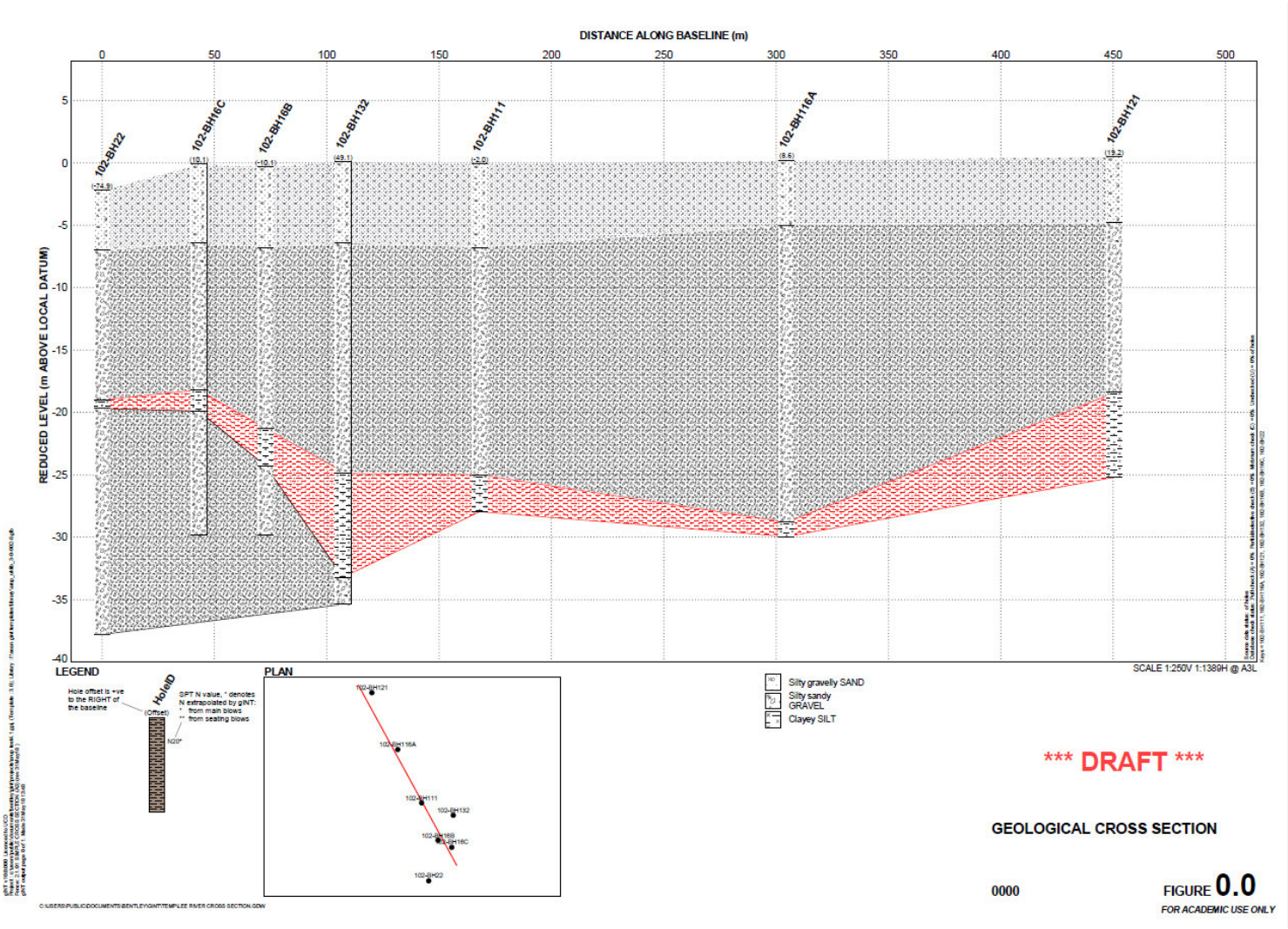


Figure 4: Data input to gINT geotechnical software

2.2.4 Geophysical Surveys

A number of ERT surveys were carried in two separate site visits. Surveys were carried out for the purpose of potentially identifying Gortian clay deposits within the glacial gravels and achieving a range of apparent resistivity values to aid future geophysical surveys. A geophysical survey could also be used to examine the nature and shape of the boundary with the overlying and/or underlying material. In the early stages of the study, it was also used as a method to scout potential sampling sites for the possibility of drilling a borehole.

Figures 5 to 8 show the location of 6no. usable ERT profiles collected from different sites throughout Cork City where interglacial deposits had been identified in adjacent boreholes.

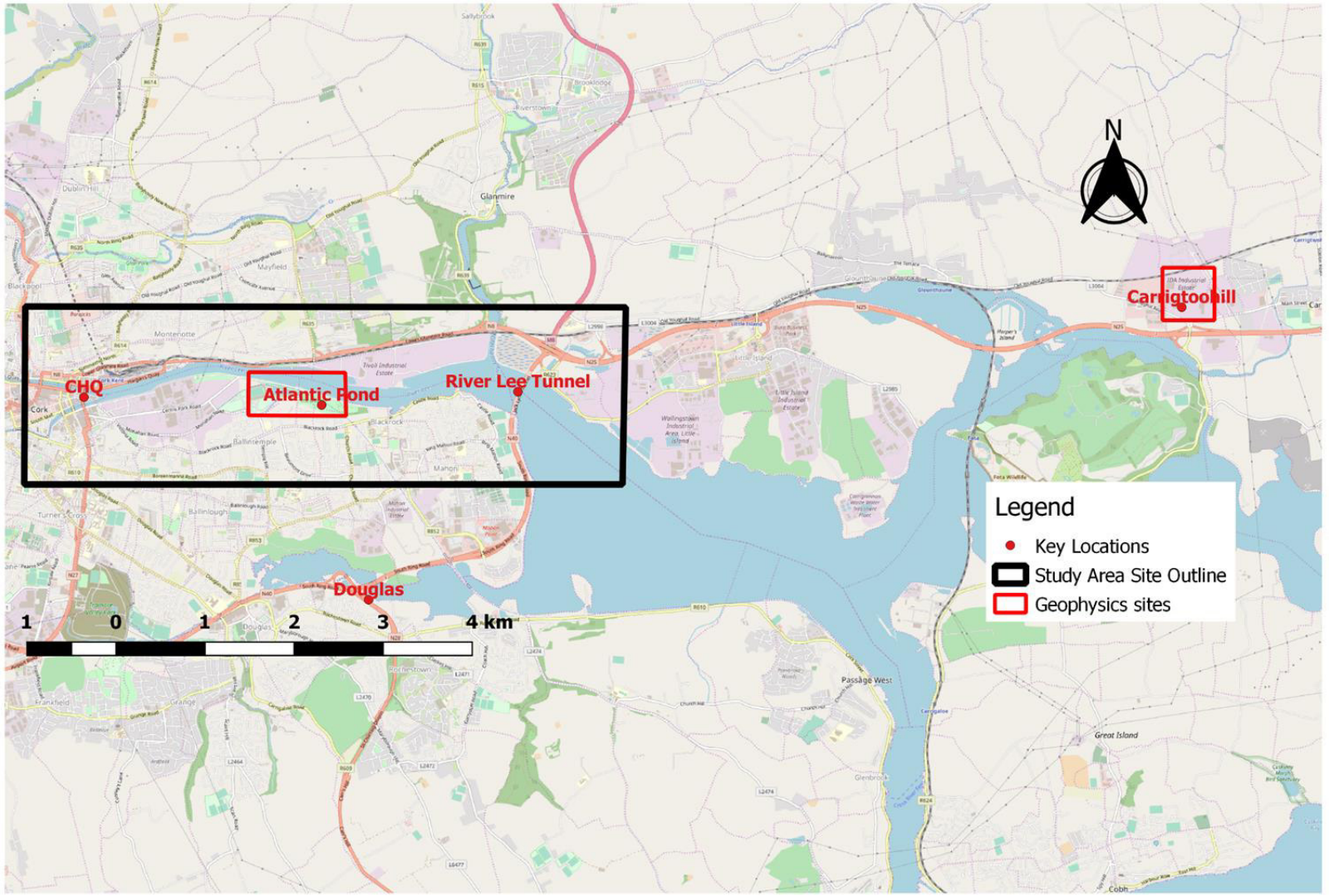


Figure 5: Plan of resistivity survey site locations

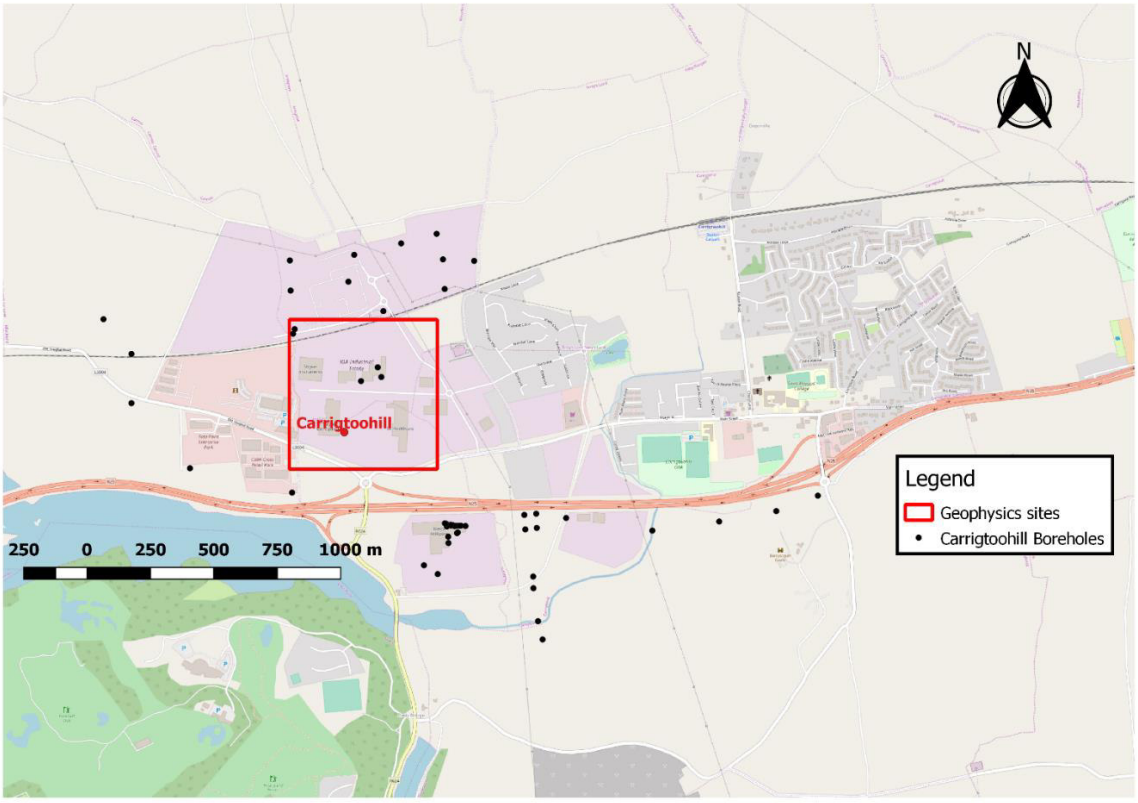


Figure 6:Plan of Carrigtoohill IDA showing nearby borehole and Trial pit locations

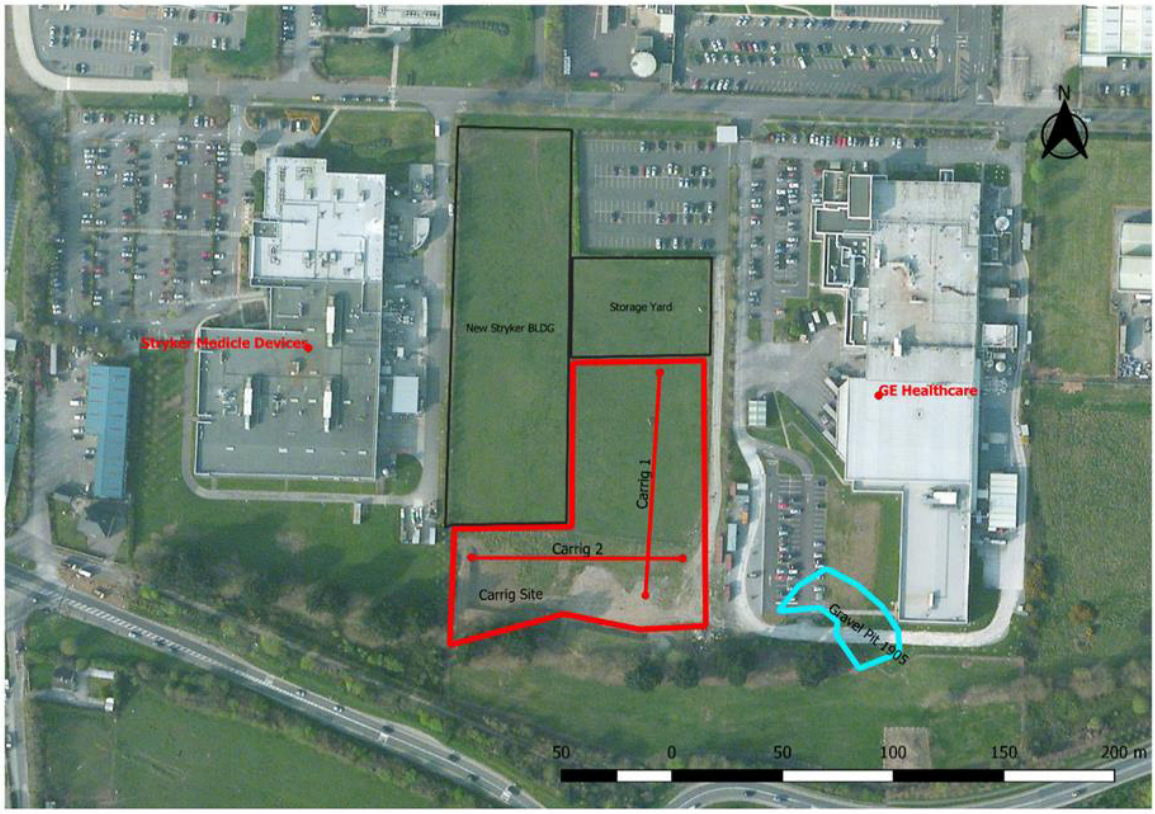


Figure 7: Plan of IDA Carrigtoohill site showing survey line locations and updated with new existing buildings.

Figure 8: Plan of resistivity surveys at Atlantic Pond/ Marina Park locations

2.2.5 Test data from past SI projects

At the time of this report much of the interpretation of past SI report in situ and laboratory testing was still in the early stages. A much more detailed examination and comparison of test results will be available in the final MEngSC thesis from this project.

Figure 9 shows the results from all PSD testing found in the deposits. Results show the interglacial deposits contain far more variation than originally thought, suggesting a potential difference in depositional environment across the study area.

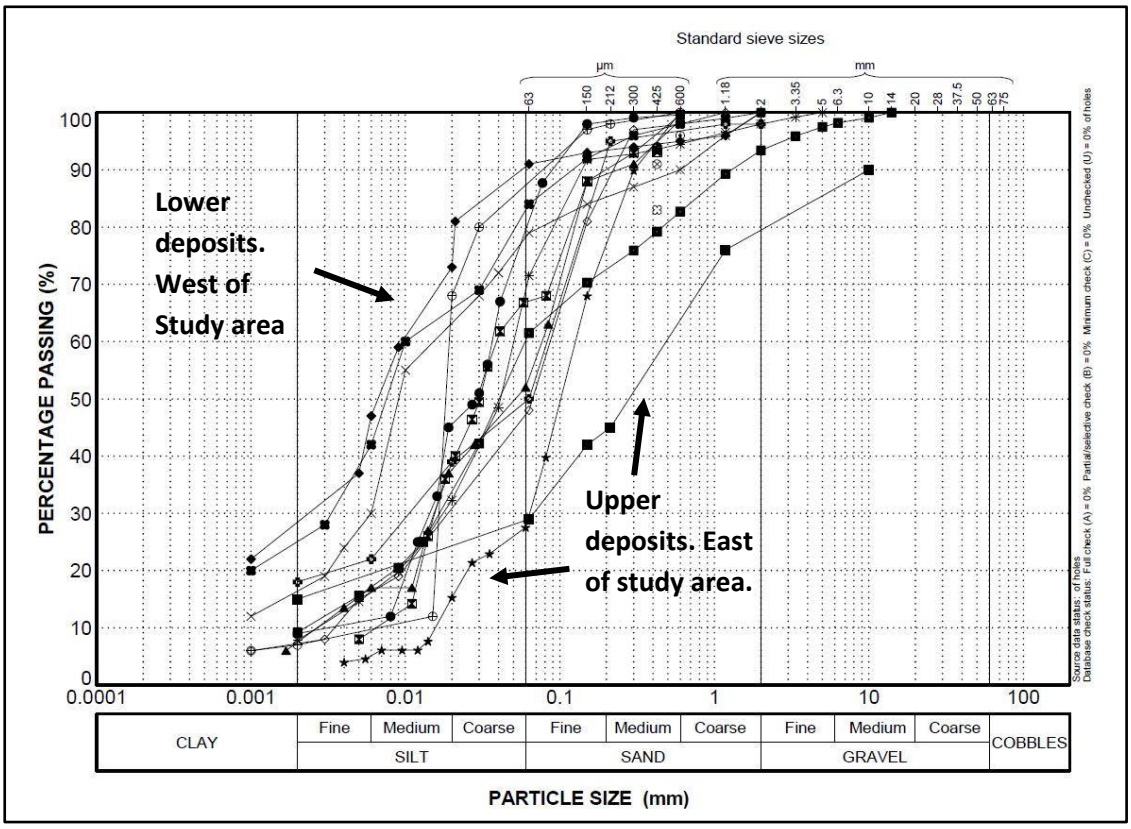


Figure 9: PSD Results from past SI projects.

Figures 10 and 11 show the level of variation in compositional properties within the interglacial deposits. From much of the data, the deposits can be divided into two distinct groups. Deposits to the east of the study area, previously suggested by Coxon (2001) as containing the full interglacial sequence, contained more organic rich, peaty material in the lower 2 – 3m of the interglacial body.

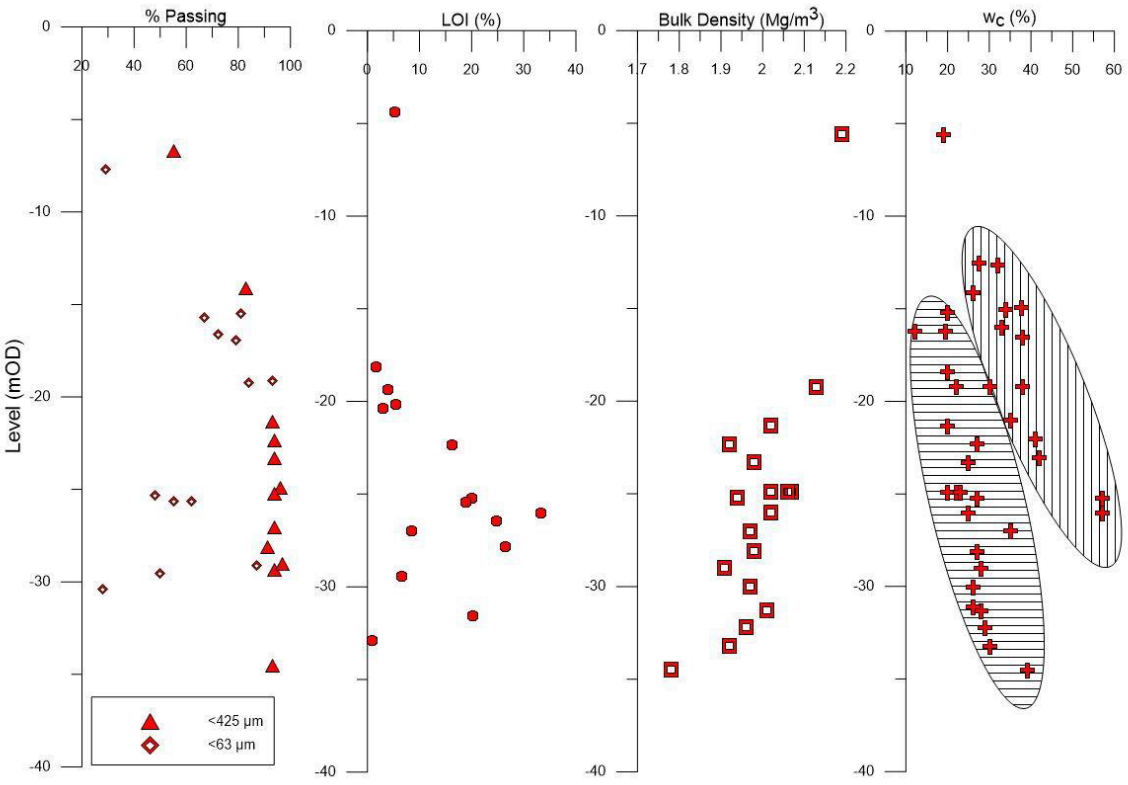


Figure 10: PSD, LOI, Bulk Density and Wc data across multiple site investigation projects.

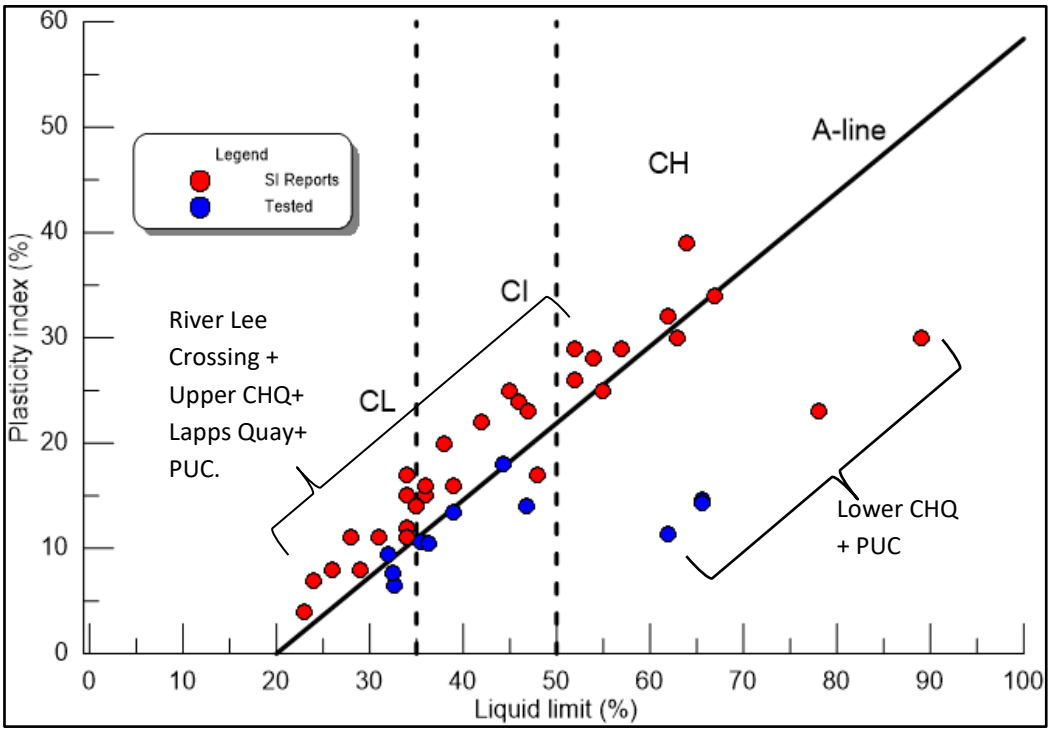


Figure 11: Plasticity A-Line Chart

7no. total 1-dimensional Oedometer compression tests were found in past reports, seen in Figure 12. The oedometer results appear reasonable, displaying trends characteristic of a typical test on material recovered from U4 samples. The curved shape of the tests suggest that the material has retained its past structure and should help indicate some of the deposits past stress history. The increasing void ratio (e_o) values correspond to variations in W_c between the tests. Tests with higher e_o values may suggest the material is more organic rich.

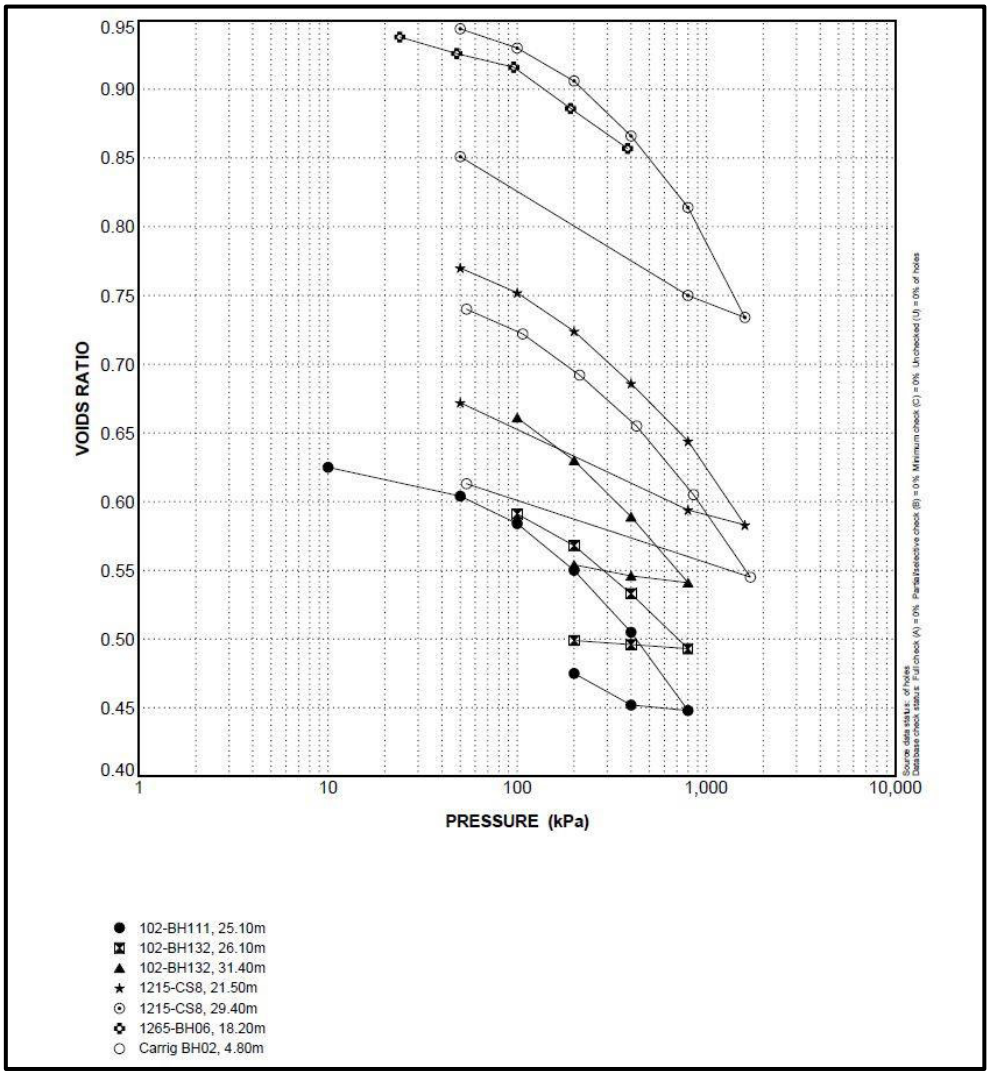


Figure 12: Past SI report Oedometer test results.

Sample/ Test	Test type	Depth(mbgl)	c_u (kPa)	c' (kPa)	Φ'(degrees)
CHQ CS8-30	UU	23.4	280		
CHQ CS9-13	UU	17.1	166		
CHQ CS9-18	UU	22.1	90		
R.Lee BH132 U6	UU multistage	27.1	28		
R.Lee BH111 U6	UU	25.1	111		
R.Lee BH132 U9	UU multistage	30.1	45		
R.Lee BH132 U7	CIUC	28.2	225	20	32
Cork athletic Grounds 1248	UU	18.2	138		
Cork athletic Grounds 1209	UU	16.8	207		
Cork athletic Grounds 0544	UU	14.5	127		
Cork athletic Grounds 0674	UU REMOULDED	15.3	49		
Lapps Quay BH4 2724	UU	19.1	150		
Cork Main Drainage BH 54/22	UU	19.3	115		
Cork Main Drainage BH 54/24	UU	20.3	135		
Cork Main Drainage BH 54/26	UU	21.3	230		
Cork Main Drainage BH 55/21	UU	15.3	195		
Cork Main Drainage BH 55/29	UU	19.3	215		
Cork Main Drainage BH 59	UU	18.7	190		
Cork Main Drainage BH 57/33	CU	30		20	34
Cork Main Drainage BH 57/38	CU	34		40	31

Table 2: Triaxial Testing Results

Table 2 displays the data available from triaxial testing results from past site investigation reports, predominantly undrained shear strength (c_u). Triaxial testing is mainly done by way of undrained unconsolidated (UU) triaxial. Results from UU testing can be of variable quality, multistage UU tests show a particularly erroneous result and so are omitted from the study. However, c_u results display a natural variation in the material, ranging from 90 – 280 kPa, classifying the material as stiff to very stiff according to BS:5930 (2015).

Figure 13 shows the variation in c_u with depth. Except for two tests, a trend of decreasing c_u values with depth exists. Examination of c_u/σ_{vo}' indicates decrease in over consolidation ratio (OCR) with depth, approaching normal consolidation at approx. 25mbgl. Examination of triaxial results from soil sensitivity values indicates S_t values of 1 – 4, indicating low sensitivity, typical behaviour for Irish glacial soils.

The SPT value results shown in Figure 14, display an increasing with depth trend. SPT N-values range from 7 – 211, predominantly between 40 – 60, with an average N-value of 55. This is indicative of a stiff to very stiff material according to BS:5930 (2015). The SPT results also reflect the changes in material composition. The suspected organic/ peaty material low in the sequence to the east of the study area displaying low N-value between depths of -25 and -30 mOD.

Soil strength parameters are examined in much greater detail in the project thesis.

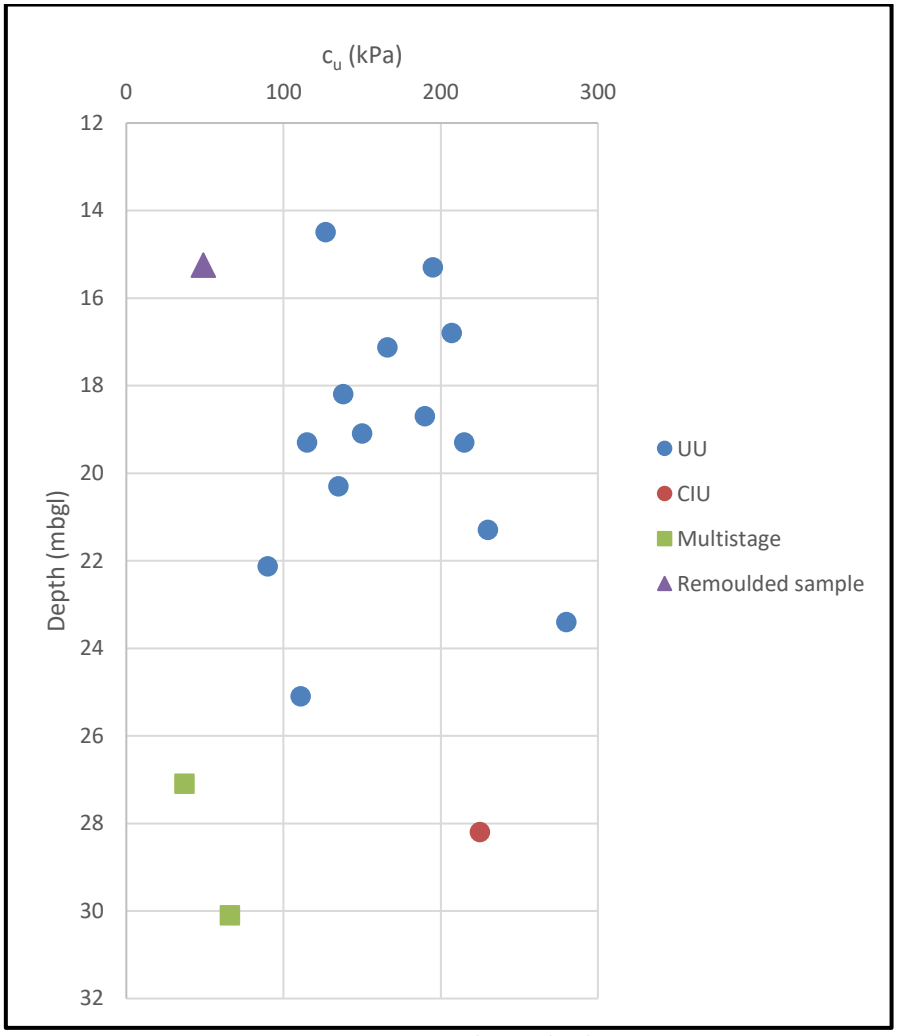


Figure 13: Triaxial c_u vs. depth

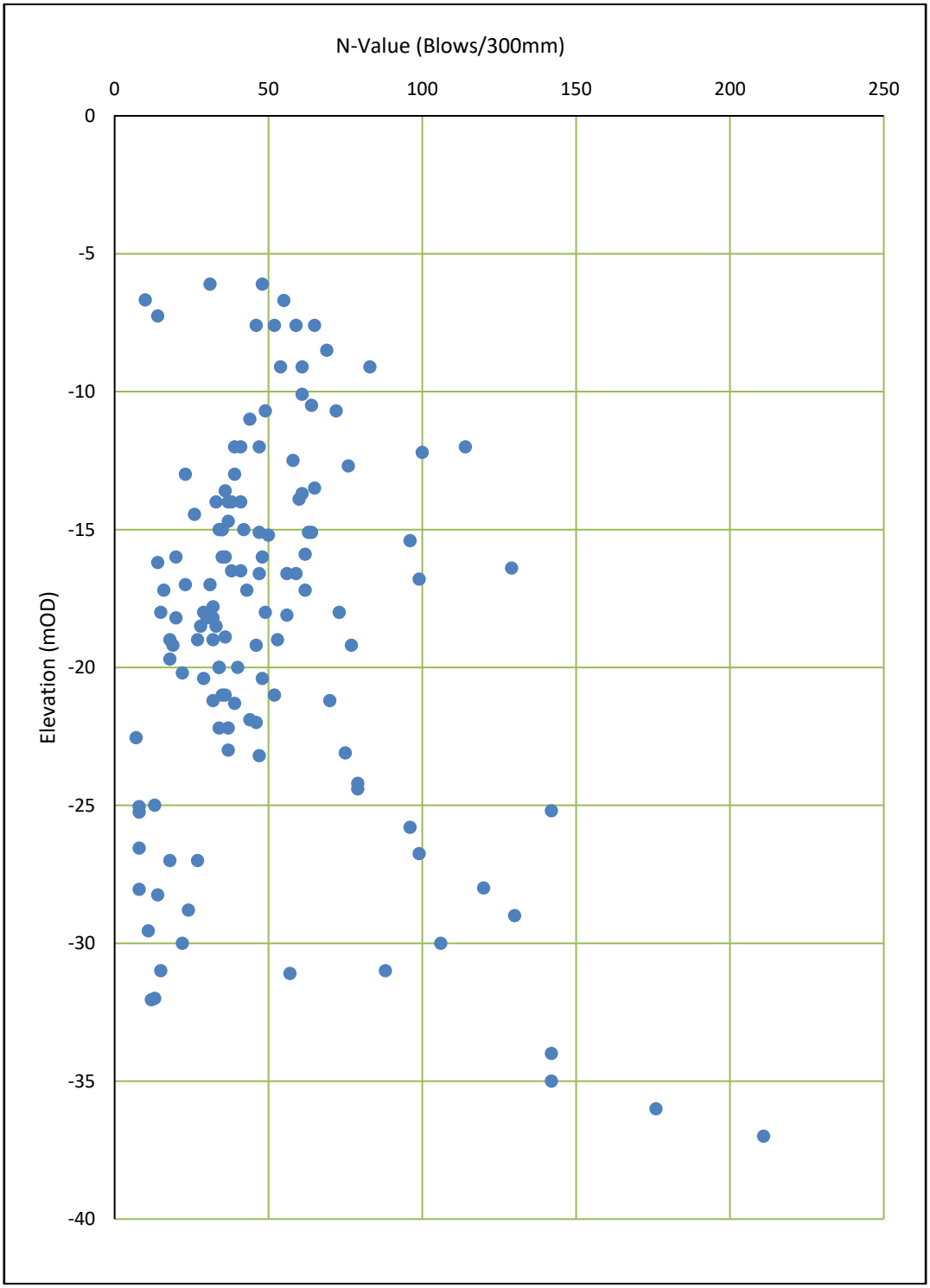


Figure 14: SPT N-Value vs. depth.

2.2.6 Lab Data

Samples were obtained from Prof. Pete Coxon of Trinity College, originally collected as part of the Dowling (1997) study investigating the same interglacial deposits at CHQ. Material from 17no. halved U4 samples were tested in the geotechnical lab in UCD. The materials' compositional properties were tested including Atterberg limits, loss on ignition, Particle Density and Particle Size Distribution. Some results are outlined in Figure 15.

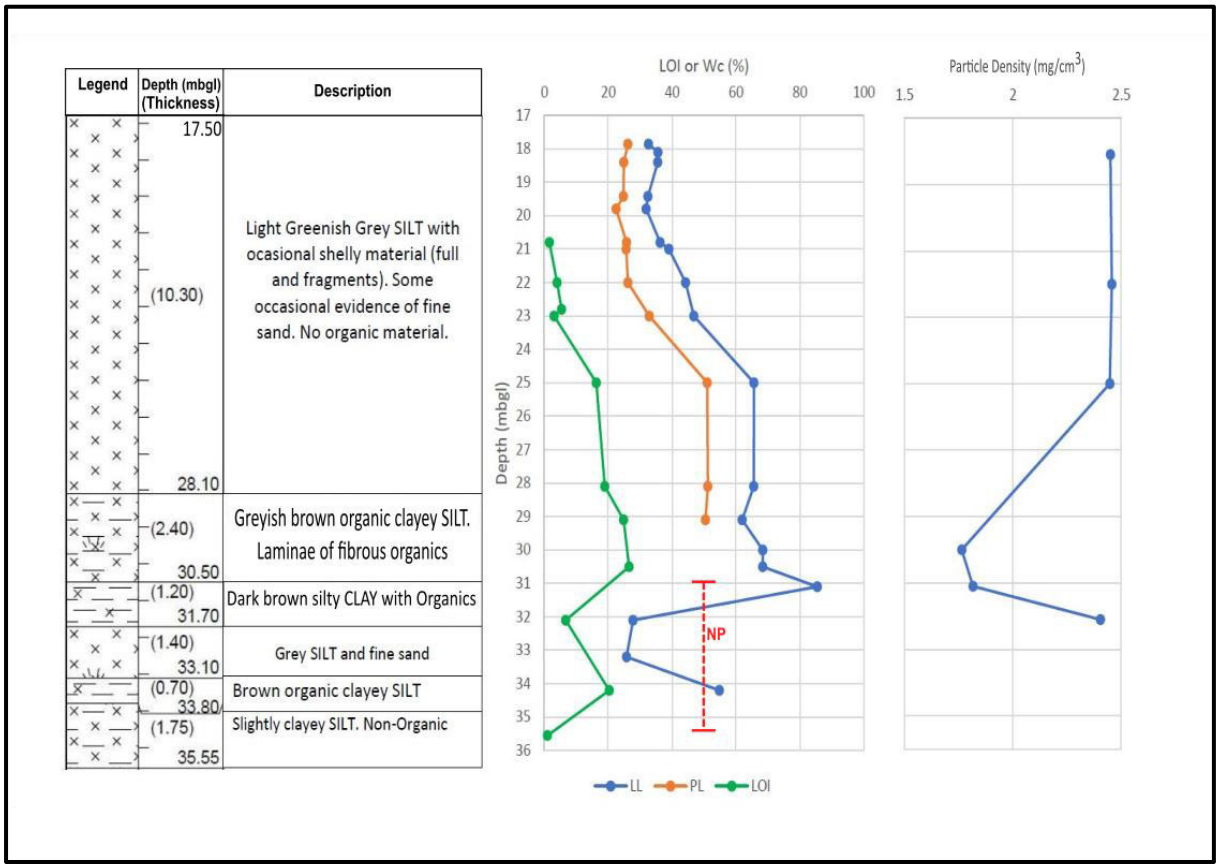


Figure 15: Samples Lab test results

The materials' "intrinsic properties" were tested in relation to a framework outlined by Burland (1990). These samples were "reconstituted". This process involves the destruction of all structure and fabric in the material before rehydrating to a moisture content 1.25 times the liquid limit to examine the materials inherent properties. Reconstituted samples are tested by Oedometer, 1-D compressional tests and the results compared to the undisturbed Oedometer tests from past SI projects. The results are compared in relation to the Intrinsic Void Index (I_v) normalisation to examine the depositional and compressional history of the material, shown in Figure 16. This is examined in far more detai in the resulting MEngSC thesis.

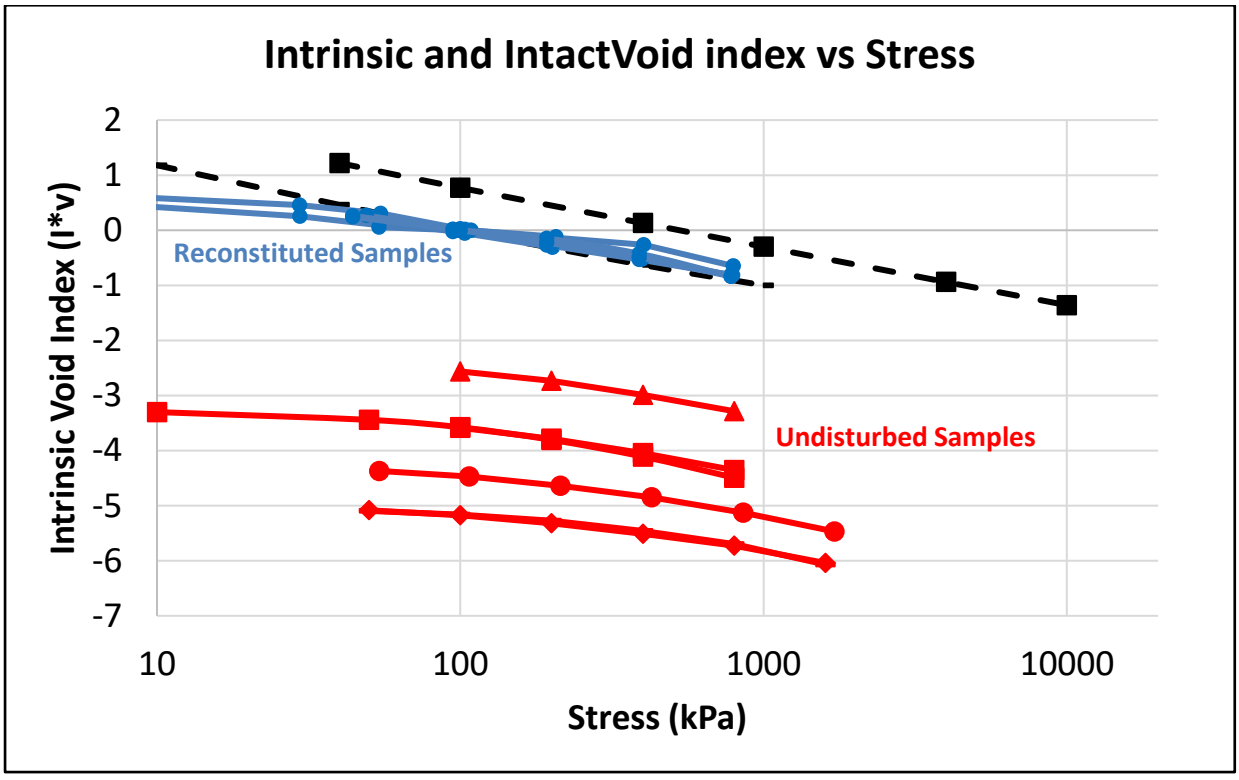


Figure 16: Reconstituted and Undisturbed Void Index Properties

2.2.7 Data Processing and interpretation.

Data from past SI reports and the collected lab data were combined to characterise the materials composition, strength and engineering parameters. Differences in the material sequences laterally and vertically were examined with possible changes in the depositional environment identified. Geospatial data collected examining the distribution of interglacial deposits and rockhead topography is displayed using ArcGIS. Numerous maps and cross sections were created which are available in the appendix section of this report.

This data is displayed and compared clearly in the MEngSC thesis currently in production as part of this project.

2.2.8 Report and thesis write up

As previously noted, this project is still ongoing and due for completion in January 2019. This stage and previous data interpretation are still ongoing. Upon completion, the full thesis and all spreadsheet and database information will be made available to the GSI.

2.3 Outputs

The outputs for the project are as follows:

- An understanding of the distribution of the Gortian Clay in Cork City including strata elevations and thicknesses.
- Contour maps displaying rockhead topography and Gortian Clay distribution.
- A set of two-dimensional cross-sections for the entire study area.
- A gINT geotechnical database for the boreholes in the area from which geotechnical borehole logs and cross sections can be generated.
- A geo-referenced database of borehole locations containing interglacial deposits and rockhead and associated lab and in-situ test results.
- Database of tables and graphs containing geotechnical testing results. This will form a useful toolset for any future site investigation project in the city.

An immediate impact of this project is the creation of the attached bedrock and interglacial distribution maps. With the recently proposed plans for the expansion of the area east of Cork City, there is a high likelihood that construction projects will encounter these stiff clays. These maps will be a very useful guide in the desk study stage of any geotechnical site investigation. The database of testing reports would prove a useful tool for any engineering consultancy, geotechnical contractor, planner or developer. It will contain a summary of past test results and engineering parameters for the interglacial clay. This would potentially limit the testing necessary for a project or provide a suitable benchmark from which to QC their own test results.

Task No.	Deliverable description	Planned delivery (as per proposal)	Date of delivery
1	Definition of Study Area	21/02/2018	21/02/2018
2	Source and assessment of borehole and test data.	01/04/2018	01/04/2018
3	Learning of GIS, gINT etc. Input of data and the development of geospatial datasets etc.	31/05/2018	31/05/2018
4	ERT surveys - Scouting, fieldwork, processing. (2 visits)	01/08/2018	01/08/2018
5	Laboratory work, including sourcing of samples, learning test methods, calibration of equipment, carrying out and analysis of all testing	01/09/2018	01/09/2018
6	Report and Poster for GSI	06/11/2018	06/11/2018
7	Production of MEngSC Thesis	01/01/2019	01/01/2019

Publications to date:
No data published.

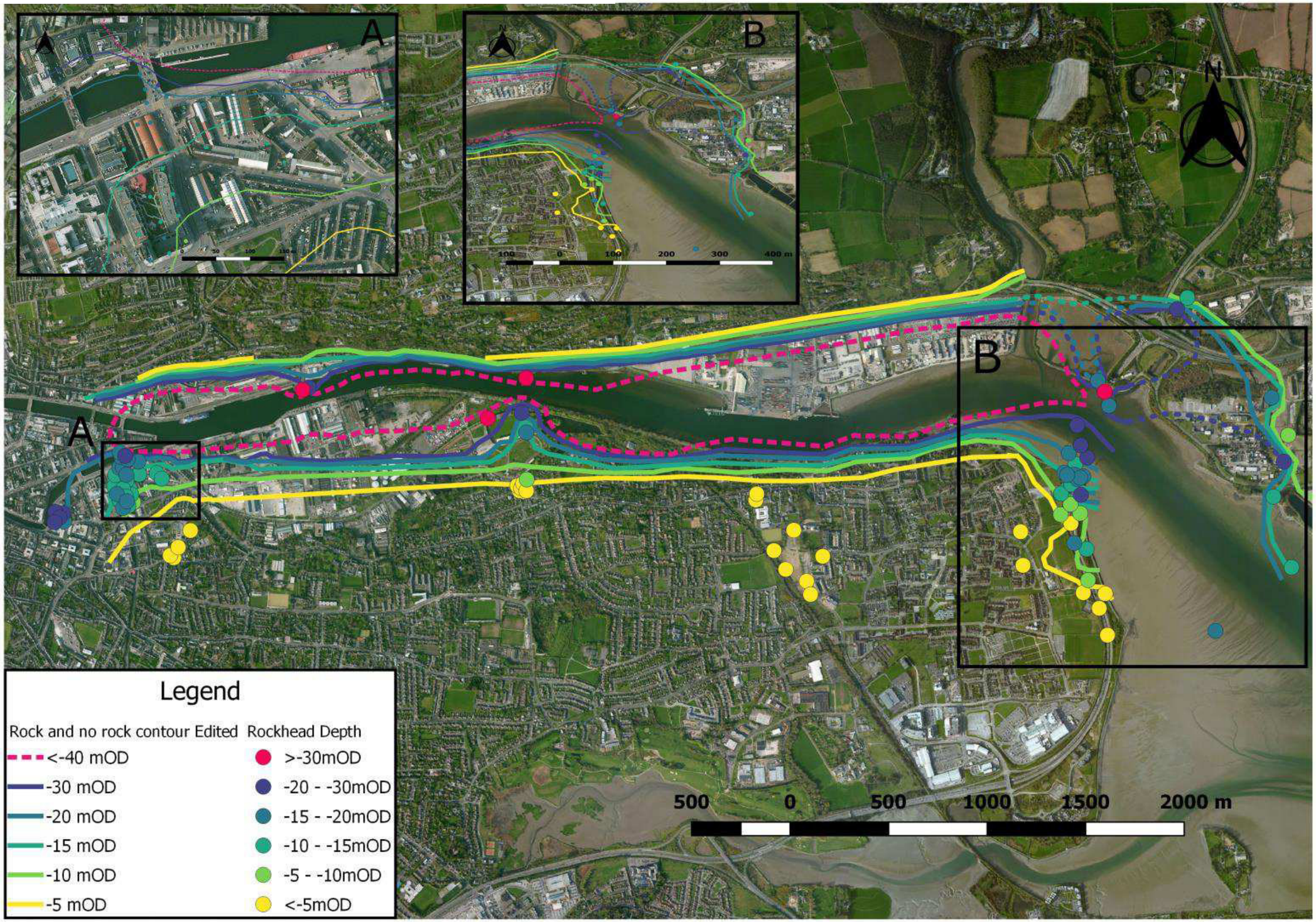
4. Data/outputs submitted with final report *(please list the documents, presentations, datasets etc. submitted with this report)*

a. Rockhead Topography contour of Study area.
b. Map of boreholes encountering interglacial deposits.
c. Spreadsheet of Borehole locations encountering clay
d. Spreadsheet of Borehole locations encountering Rockhead

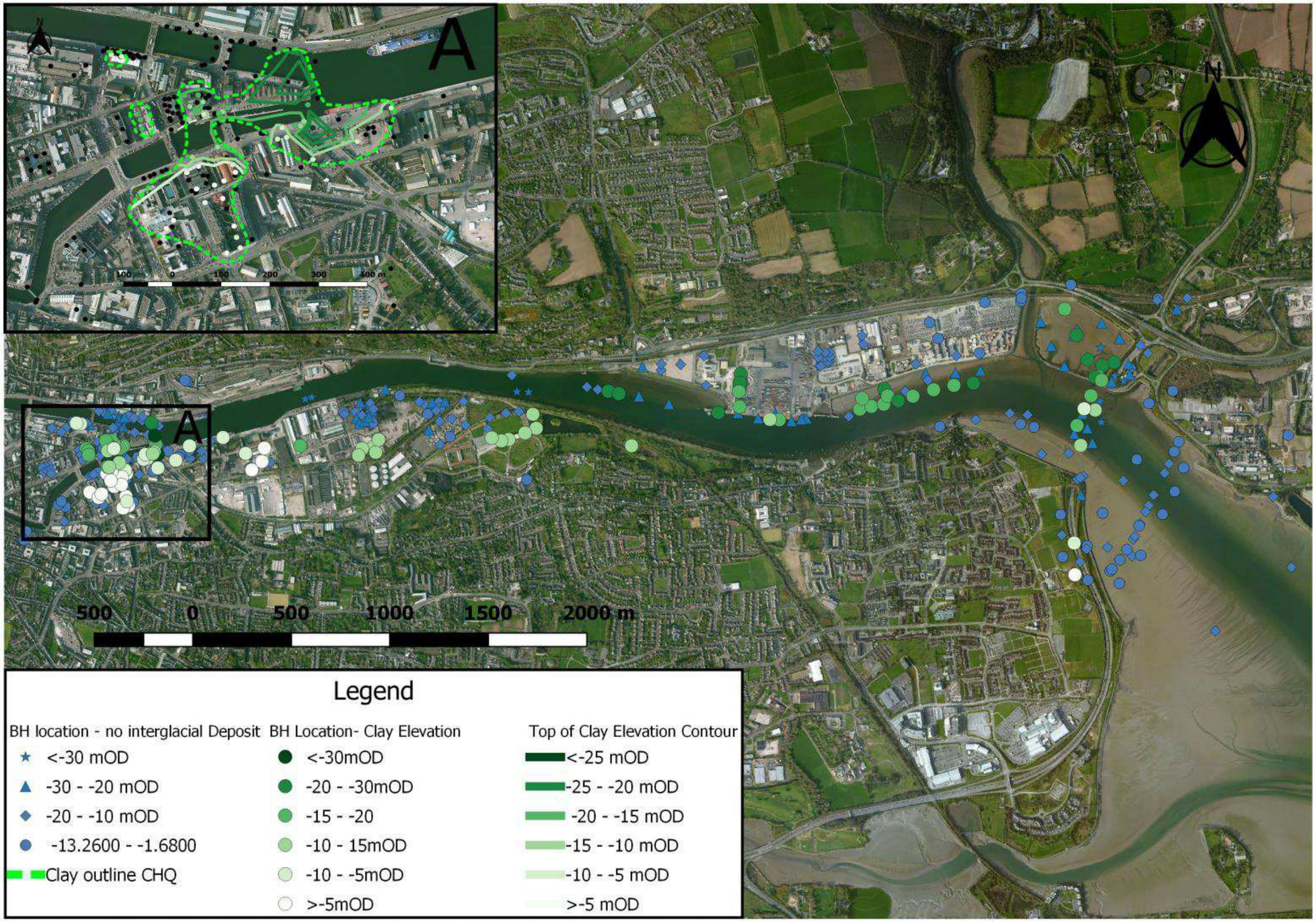
5.0 References

Allen, A. R. and Milenic, D. (2007) 'Groundwater vulnerability assessment of the Cork Harbour area, SW Ireland', *Environmental Geology*, 53(3), pp. 485–492. doi: 10.1007/s00254-007-0670-5.
Burland, J. B. (1990) 'On the compressibility and shear strength of natural clays', *Géotechnique*, 40(3), pp. 329–378. doi: 10.1680/geot.1990.40.3.329.
Coxon, P. (2017) *Advances in Irish Quaternary Studies*. doi: 10.2991/978-94-6239-219-9.
Devoy, R. J. N., 1983, Interglacial deposits in Cork Harbour. *Irish Quaternary Association Newsletter*, 6, 14-15.
Devoy, R. J. N., 1984, Quaternary environments in the area of Cork city. *Irish Quaternary Association Newsletter*, 7, 1-18.
Dowling, L. A. (1997) 'A palynological investigation of interglacial sediments in Cork Harbour'.
Dowling, L. A. and Coxon, P. (2001) 'Current understanding of pleistocene temperate stages in Ireland', *Quaternary Science Reviews*, 20(16–17), pp. 1631–1642. doi: 10.1016/S0277-3791(01)00028-2.
Farrell, E. R. and AGL Consulting (2016) '1 ST HANRAHAN LECTURE GEOTECHNICAL PROPERTIES OF IRISH GLACIAL AND INTERGLACIAL SOILS', in, pp. 1–19.
Long, M. *et al.* (2015) 'Deep excavations in water-bearing gravels in Cork', *Quarterly Journal of Engineering Geology and Hydrogeology*, 48(2), pp. 79–93. doi: 10.1144/qjegh2014-098.
Mitchell, G. F. (1970) 'The Quaternary Deposits between Fenit and Spa on the North Shore of Tralee Bay , Co . Kerry', *Proceedings of the Royal Irish Academy. Section B: Biological, Geological, and Chemical Science*, 70, pp. 141–162.
O'Connor, S., O'Connor, P. and Long, M. (2016) 'Resistivity of Irish glacial deposits', *Proceedings of the Institution of Civil Engineers - Geotechnical Engineering*, 169(1), pp. 49–66. doi: 10.1680/jgeen.14.00141.
Scourse, A. J. D. *et al.* (1992) 'New Evidence on the Age and Significance of the Gortian Temperate Stage : A Preliminary Report on the Cork Harbour Site', *Royal Irish Academy. Section B: Biological, Geological and Chemical Science*, 92B, pp. 21–43.
W.P.Warren (1979) 'Warren WP_The_Stratigraphic_Position_and_Age_of_the_Gortian Dep.pdf', *Geological Survey of Ireland Bulletin*, 2, pp. 315–332.

6.0 Appendix



Appendix A: Rockhead contour map showing borehole data on graduated scale



Appendix C: Plan of interglacial borehole data showing stratigraphic level on graduated scale.