Cork Lower Harbour Main Drainage Scheme. Estuary Crossing Feasibility Report

Cork Dockyard to Monkstown

Nicholas O'Dwyer Ltd.
Unit E4
Nutgrove Office Park
Nutgrove Avenue
Dublin 14, Eire

For
Irish Water, Dublin

A supplementary Feasibility Study Report in respect of the installation of pumped sewer mains by trenchless methods between Cork Dockyard and Monkstown.
Tender Enquiry Ref: 20506/cor/ck150414

Boregis Ltd

132 Maney Hill Road

Sutton Coldfield B72 1JU

United Kingdom

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1. EXECUTIVE SUMMARY

The existing sewer network serving the Lower Cork Harbour area comprises mainly combined sewer systems. Wastewater from Cobh, Carrigaline, Passage West/Monkstown and Ringaskiddy is currently discharged untreated into the Harbour.

The proposed scheme – Cork Lower Harbour Main Drainage Scheme – will provide, for the first time, secondary wastewater treatment via a new 80,000pe wastewater treatment plant in Shanbally and make improvements to the sewer pipeline network and infrastructure.

As part of the scheme, two pumped force main pipes of approximately 830m length are required to transfer sewerage from headworks at the Dockyard Pumping Station to Monkstown across the River Lee estuary.

Nicholas O'Dwyer Ltd. (NOD) acting as Consulting Engineers on behalf of Irish Water (formerly Cork County Council) have delivered a preliminary design for the proposed crossing based upon the installation of twin pipelines by trenchless methods. A pipe diameter range of 450mm to 560mm Outer Diameter (OD) is under consideration and will be finalised during the detailed design stage. For the purpose of this report a diameter of 500mm OD has been assumed.

Site visits were undertaken with representatives of NOD on 16 June 2014 and 22 September 2015. The observations made have been used to inform the preparation of this report.

Historical maps from the late 19th and early 20th century indicate that the only significant change in the physical terrain in the area of the crossing was the establishment of Cork Dockyard, which was built on reclaimed land at the mouth of the River Lee.

The general bedrock geology underlying the site is Flaser-bedded sandstone & mudstone on the east and sandstone with mudstone & siltstone on the west.

A comprehensive coverage of subsurface and non-disruptive investigation studies for the project has been undertaken including physical and non-disruptive geophysical investigations at Cobh, Monkstown and below the marine environment within West Passage.

Investigations to date have found that relatively weak, often fractured, sedimentary rocks lie below bedded alluvial and glacial deposits of silt, gravel and boulder clay units. Generally gravel, containing cobbles, was found to lie above the bedrock. This gravel is permeable and groundwater held within this layer by a capping layer of silt above, especially on the western side and Monkstown.

Dredging of the crossing is less desirable than trenchless methods from an environmental viewpoint due to the inevitable impact on the marine and foreshore environments.

Of the potential trenchless methods, only Horizontal Directional Drilling (HDD) and conventional tunnelling are considered technically viable for the alignment under consideration.

A preliminary relative review of probable costs has established that HDD is expected to be the most economic viable trenchless solution.

The main drilling related environmental risk identified is the risk to aquatic life in water courses and the marine environment from the release of drilling fluids (inadvertent returns). Maintaining sufficient depth (see Section 9.3.3 Vertical Profile) within competent bedrock is the main means of risk mitigation, combined with good contingency measures to manage and clean up any breach.

Due to space limitations for pipe laydown at Cobh it is envisaged that the drilling of two separate bores will take place from Cork Dockyard towards Monkstown with two 500mm OD HDPE pipes pulled in from a pipe laydown area extending west along Glen Road.

The maximum reamed diameter for each pipe installation is anticipated to be around 750mm.

It is required that the drilling intersect the locations of the proposed pumping station at Cork Dockyard and the interception manhole at Marine Villas, Monkstown. High accuracy steering and positional monitoring will be required to meet the latter requirement.

A minimum main crossing elevation of at least -36mOD elevation is anticipated to maintain the drilling within the bedrock at the deepest point and limit the interface with gravels and very soft silt overlying the bedrock. A main installation elevation at -50m will reduce the degree to which fractured rocks may be present. A single low point is proposed to maximise hydraulic performance of the completed pipelines.

At Monkstown, mitigating the risk of drilling fluid loss to the environment as the drill passages with limited cover depth may be achieved by temporarily encasing the final section of the alignment to the reception site adjacent to Glen Road.

Curve radii should be maximised to the extent possible to minimise the stresses on the pipe during pull-in and to help with steerage control during pilot drilling.

The diameter and length required for this crossing is within the capabilities for the larger drilling contractors employing the larger "maxi" type drilling rigs. The complex and fractured geology make the crossing very challenging, however once the recommendations contained within this report are appropriately considered and actioned we consider the crossing to be technically feasible and manageable in terms of safety, constructability and environmental and financial risk.

2. INTRODUCTION

The existing sewer network serving the Lower Cork Harbour area comprises mainly combined sewer systems. Wastewater from Cobh, Carrigaline, Passage West/Monkstown and Ringaskiddy is currently discharged untreated into the Harbour.

The proposed scheme – Cork Lower Harbour Main Drainage Scheme – will provide, for the first time, secondary wastewater treatment via a new 80,000pe wastewater treatment plant in Shanbally and make improvements to the sewer pipeline network and infrastructure.

As part of the scheme, twin pumped DN500 sewer pipelines of approximately 830m length are required to transfer sewerage from the Dockyard Pumping Station at Cork Dockyard (in Cobh) to Monkstown across the River Lee (Appendix B, Figure 14).

Nicholas O'Dwyer Ltd. (NOD) acting as Consulting Engineers on behalf of Irish Water (formerly Cork County Council) are developing the preliminary design for the required crossing.

NOD has retained Boregis Ltd to develop an independent feasibility report for the Estuary Crossing Pipeline the original scope for which was set out in a tender invitation letter of 15 April 2014 ref 20506/cor/ck150414. This new report has been commissioned to report on the feasibility of a Horizontal Directional Drill (HDD) crossing from Cork Dockyard to Marine Villas (adjacent to Sand Quay) in Monkstown, and will be included in the Cobh 146B Planning Application to An Bord Pleanala.

The work for this project has been undertaken by Mr Andy Robinson, a specialist in underground pipeline installations by trenchless methods, including HDD and tunnelling, with over 30 years' experience in the trenchless field. A copy of Mr Robinson's CV can be found at Appendix D.

Figure 1 – Monkstown and the River Lee

3. PROJECT SCOPE

The scope of this report focusses upon:

- The feasibility of the proposed estuary crossing from Cork Dockyard to Marine Villas, Monkstown;
- Review of the risks and appropriate risk management associated with the current design
- The constraints associated with the preliminary design;
- Constructability by Horizontal Directional Drilling (HDD);
- Environmental risk and mitigation associated with the proposed construction technique.

4. SITE VISITS

Site visits were undertaken with representatives of NOD on 16 June 2014 and 22 September 2015. The observations made have been used to inform the preparation of this report.

5. HISTORICAL SETTING

Historical maps from the late 19th and early 20th century (Appendix A) indicate that the only significant change in the physical terrain in the area of the crossing was the establishment of Cork Dockyard, which was built on reclaimed land at the end of West Passage.

The historical mapping for the west side of the crossing at the centre of Monkstown shows the area is little changed. The most notable observation appears to be the realignment of the water course which previously meandered through the flat grounds and has been relocated in recent times immediately adjacent to Glen Road.

Figure 2 - Water course adjacent to Glen Road

6. SITE GEOLOGY

This section of the Report reviews the geological context and investigations that have been undertaken for the project to date. The subsurface geology is complex, and this complexity has benefitted from the thorough evaluation by geologist Dr. Ivor MacCarthy in his report, *CORK LOWER HARBOUR MAIN DRAINAGE SCHEME Geology of the Cork Dockyard-Monkstown Estuary Crossing* which can be found in Appendix E.

The following sub sections consider the investigation information and Dr. MacCarthy's evaluation in order to consider the relevance to the installation methodology proposed and to assess the suitability of the conditions for the installation method.

The complex and fractured nature of the geology discussed below makes the crossing challenging, however they are, in our view, within the capability of an appropriately experienced drilling contractor employing appropriate design and means and methods of work.

6.1. Geotechnical Setting

The GSI 1:100,000 scale geological mapping (Figure 3) indicates that the bedrock below the site varies generally from east to west and north to south. There are also faults in the bedrock to be traversed by the crossing route as well as folded or inclined bedding.

The principal geological description on the east side of the crossing is Flaser-bedded sandstone & mudstone. On the west side the geological description is Sandstone with mudstone & siltstone.

Conodate Geology, who provided petrographic testing to Causeway Geotechnical (discussed later), included a general description of the geological setting of the site in their report. This was apparently based upon the GSI mapping and geological memoir as follows:

> *The lithology of these samples is consistent with the local geology of Cobh / West Passage as defined on the GSI 1:100,000 Bedrock Map of South Cork. These samples are in the Uppermost Devonian and Carboniferous Marine Sandstones and Shales – The Cork Group. These lithologies would have been deposited in the central Munster Basin during the upper Devonian and Lower Carboniferous. These units represent tidally influenced depositional environments.*
>
> *Based on the descriptions of the lithological units in the area from the GSI Memoir (Sleeman & Pracht, 1994), the samples have been assigned possible formation names, which would have to be confirmed by the geologist on the ground.*
>
> *The laminated mudrock, siltstone and sandstone with mudrock intraclasts (BH 07-EC, 21.00m, BH 07-EC, 43.00m, BH 08-EC, 25.00m and BH 09-EC, 43.00m) are comparable with the Gyleen Formation.*

The flaser-bedded sandstone and mudrock samples (BH 05-EC, 22.40m and BH 05-EC, 44.60m) grey sandstone with convolute bedding (BH 04-EC, 30.00m) are consistent with the Old Head Sandstone Formation (Upper Devonian).

Figure 3 - Geological data copyright DCMNR and Government of Ireland. Image base Digital Globe, GeoEye & Microsoft 2014

A fuller evaluation of the regional geological setting for the area can be found at Part B of Dr. Ivor MacCarthy's, *CORK LOWER HARBOUR MAIN DRAINAGE SCHEME Geology of the Cork Dockyard-Monkstown Estuary Crossing.*

6.2. SITE INVESTIGATIONS

NOD on behalf of Irish Water commissioned a comprehensive coverage of subsurface and non-disruptive investigation studies for the project. Specifically, the following studies have been reviewed in the preparation of this Report:

- 14/02/2014 – Causeway Geotech – 13-381 – DATA – Harbour
- 14/02/2014 – Causeway Geotech – 13-381a – INTERPRETIVE – Harbour
- 06/03/2014 - Minerex Geophysics - 5721f-005 – GEOPHYSICAL - Passage West & Monkstown
- 04/03/2014 – Apex – AGL13120_01 V2 – GEOPHYSICAL – Cobh (pipelines)
- 04/03/2014 – Apex – AGL13120_01A V2 – GEOPHYSICAL – Cobh (pumping sites)
- 03/04/2014 - PGL Priority – P13097_Rp_D01 (Vols 1 to 3) – DATA - Cobh
- 11/04/2014 - PGL Priority - P13101_Rp_D01 (Vols 1 to 3) – DATA - Passage West & Monkstown
- 04/07/2014 - PGL Priority - P13101_ Rp_D01_Int – INTERPRETIVE - Passage West & Monkstown
- November 2015 – PGL Priority Geotechnical - 8 borings/rock cores and additional trial pits at Cork Dockyard – P13097A.

- May 2016 - Priority Geotechnical boreholes, core logs and some test results for EC2 marine boreholes.

The studies cover the three main sections of the proposed crossing, ie Cork Dockyard, River Lee/Passage West marine section, and Monkstown. The relevant information provided for review relating to the subsurface conditions are:

1. Cork Dockyard – PGL Priority report P13097, Apex report AGL13120 and Priority Geotechnical cable percussive and rotatory borings (BH/RC01-DY to BH/RC08-DY).
2. River Lee marine crossing - Causeway Geotech reports 13-381 & 13-381a, Minerex Geophysics report 5721f-005 and the 2016 Priority Geotechnical results for seven new borings within the river, including some test results.
3. Monkstown - PGL Priority report P13101 and Minerex Geophysics report 5721f-005

In addition to the existing marine investigation records gathered to examine and confirm the feasibility of the estuary crossing by HDD methods, a supplementary marine investigation programme is currently being progressed by NOD in order to provide sufficient information for final design, contractor pricing, and construction risk mitigation purposes.

6.3. Cork Dockyard

In late 2015, on behalf of Irish Water, Priority Geotechnical undertook an additional eight cable percussive and rotatory borings (BH/RC01-DY to BH/RC08-DY) within the dockyard.

The approximate location of the boreholes is shown on project drawing 20506-SK-62 (Appendix B, Figure 15).

Additionally, a small number of earlier borings were undertaken within the dockyard and are reported on in the PGL Priority report P13097 from 04/03/2014. The location of these boreholes is shown at Appendix B, Figure 16.

Detailed analysis and review of the geology encountered within the dockyard borings can be found under PART C of Dr MacCarthy's *REPORT - CORK LOWER HARBOUR MAIN DRAINAGE SCHEME Geology of the Cork Dockyard-Monkstown Estuary Crossing.*

6.3.1. Superficial Deposits

Dr MacCarthy's Report Part C Section "*12.2 – Superficial deposits in onshore boreholes*" summarises the general sequence of superficial deposits between the made ground of the dockyard and the underlying bedrock as detailed in boreholes BH01-DY through BH08-DY and earlier 2013 boreholes and is reproduced below:

> *These consist of Boreholes BH01-DY to BH08-DY and BH16-CH, BH17-CH, BH102-CH and BH103-CH.*
>
> ***Boreholes BH16-CH, BH17-CH, BH102-CH and BH103-CH***

Information on the composition and distribution of the superficial deposits in these boreholes is summarised in Fig 19.

See PGL Priority Geotechnical report P13097 dated 22nd January 2015.

The boreholes are dominated by alternating Silty and Sandy Gravels with variable amounts of Sandy Gravelly Silt. 'Boulders' and 'Boulder Clay' are present in BH16-CH.

Boreholes BH01-DY to BH08-DY

Information on the composition of the superficial deposits is summarised in Fig 12.1.

See PGL Priority Geotechnical P13097 report dated 12th November 2015.

The vertical and lateral distribution pattern of these deposits is illustrated in Fig 12.2.

The borehole records for BH01-DY do not appear to contain sufficient information on the superficial deposits to include in Fig 24. Consequently, it is not clear to what extent the superficial formations in the adjacent boreholes extend into the area of BH01-DY.

The deposits are dominated by multi-coloured (grey, red, brown), medium dense, clayey and ***<u>sandy gravels with a high cobble content</u>*** *(emphasis added), silts and clays.*

The full borehole record in the east (BH07-DY) is dominated by gravels. Traced westwards, the Gravel formation bifurcates into (1) a lower layer that persists only as far BH03-DY and (2) an upper layer that extends at least as far as BH02-DY (Fig 12.2).

The intervening sequence between the two Gravel layers consists of Clays and Silts.

The lower Gravel layer dies out when traced southwards towards BH08-DY.

A laterally impersistent Silt layer underlies the upper Gravel layer. This is thickest in BH02-DY and BH08-DY.

Traced south-westwards from BH07-DY towards BH102-CH, the gravel-dominated sequence appears to show an increase in finer sediment grades which probably form a matrix to the gravels. This finer unit contains; Sandy silty gravels, Sandy gravelly silts, Silty sandy gravels and Slightly silty gravels.

It is likely that the gravels and possibly the sands are porous and permeable.

6.3.2. BEDROCK

The RC01-DY through RC08-DY boreholes indicate that the bedrock elevation commences just below sea level at the rear of Cork Dockyard in the vicinity of the proposed pipe launch site into the ground and is around 13m deep (10m below OD) near the quay wall.

Dr MacCarthy's Report Part C provides analysis and summary of the bedrock geology for the dockyard rotary cored borings RC01-DY through RC08-DY.

Section 7.2 of his report summarises the bedrock lithology as:

> *The bedrock is composed entirely of siliciclastic non-carbonate sedimentary rock. That comprises sandstones, claystones, siltstones and heterolithics (intricately inter-laminated sandstone/mudstones). There may also be thick (possibly up to about 15m) relatively uniform mudstone units within the succession. All of these rocks have endured tectonic deformation and low-grade metamorphism characterised by the development of a slatey cleavage in the fine-grained lithologies and a fracture cleavage in the coarser-grained lithologies.*
>
> *The bulk of the sandstones are fine- to medium-grained. However, thin coarse-grained sandstones are present at a number of isolated levels. Some of these contain scattered granules and pebbles of vein quartz usually less than about 3mm grain size. Such levels have been recognised as an important stratigraphical marker facies (sediment/sedimentary structure type) in the region known as the Garryvoe Conglomerate Facies.*

There is variation in the clay and silt content in the fine-grained rocks here. Most of the siltstones probably have between 20% and 50% clay content. They range from Siltstone to Clayey Siltstone (Appendix C2). Much of the fine-grained rocks fall into the Silty Claystone category. Much of what is listed as Claystone in Figs 7.3-7.12 is in fact Silty Claystone. There appears to be very little pure Claystone. Simple observation of the rock sequence reveals that there is little if any continuity between adjacent boreholes. Dr MacCarthy's report figures 7.1 and7.24 attempt to map the bedrock surface below ground and provide an insight into the degree of faulting, folding and other deformations within the sequence of sedimentary rocks which may be anticipated below the dockyard and the wider area.

At Sections 7.4 and 7.5 Dr MacCarthy summarises that the proposed route for the pipeline *"appears to cross-cut all discontinuities at various angles."* and, with regard to folding that *"more commonly bedding planes are inclined at angles in excess of 30 degrees due to folding of the rock layers."*

At Section 8, Dr MacCarthy notes that 30% of rock core length exhibited moderately to completely weathered rock. Furthermore, Section 9 reviews the total and solid core recovery percentages and the calculated Rock Quality Designation (RQD) indicating that the bedrock is significantly fractured with RQD values ranging from 5% to just 40%.

Section 10.2 discusses other aspects of recovered core quality and RQD from the DY cores including noting at:

> *(2) The DY boreholes here are probably cut through a lower stratigraphical level in the Cuskinny Member than the EC boreholes further south. This part of the member could be significantly different to that encountered in the earlier boreholes to the south.*
>
> *(6)Locally faulted zones are likely to be present. These would contain fractured fault breccias and disrupted bedrock masses of varying thickness and distribution.*
>
> *(7)Boreholes RC04-DY to RC07-DY show relatively shallow dipping beds of varying dips due to flexuring. This contrasts with the more steeply inclined bedding in Boreholes RC01-DY to RC03-DY.*
>
> *(9) Faults-A major fault (F8) is predicted in the Cork dockyard area. The fault zone could contain associated fractured bedrock and subsidiary splay faults.*

All of the above leads to a view that the bedrock should be expected to exhibit a complex and extremely variable discontinuity pattern.

6.4. River Lee marine crossing

Causeway Geotech originally investigated the ground conditions below the River Lee. The Report for this work, "Cork Lower Harbour Main Drainage Scheme Ground Investigation" No. 13-381, dated February 2014, has been reviewed along with the companion Interpretive Report No. 13-381a also dated February 2014.

These ground investigations were carried out in November and December 2013 to investigate previous crossing alignments. Only borehole BH07-EC is sufficiently close to the currently proposed alignment between Cork dockyard and Monkstown.

Due to the change in proposed alignment a supplementary marine investigation programme was undertaken in order to verify the proposed alignment and provide sufficient information, along with the other reports, for final design, contractor pricing, and construction risk mitigation.

The supplementary marine investigation programme was undertaken by Priority Geotechnical in May 2016 and consisted of seven boreholes and associated rock corings 01-EC2 through 07-EC2. The locations of the boreholes are shown on Figure 14 and were placed just to the north of the crossing alignment.

All seven boreholes encountered varying amounts of gravel, silt and clay deposits above the bedrock. Below these materials most boreholes encountered a small depth of gravel and cobbles of what appears to be weathered bedrock (sandstone and siltstone) material. Borehole BH04-EC2 encountered a significant depth of this material.

The underlying bedrock is predominately Sandstone though there is a notable section of Siltstone extending below the deepest part of the river channel. Mudstone was not encountered as a specific unit in any of the boreholes though the upper section of Siltstone on borehole BH04-EC2 had notable shale and mudstone bands.

BH07-EC on the west side of the Passage reports Dark Red / Purple Siltstone which is not seen in the other boreholes. This and other differences may be a result in a north/south shift in the bedrock as noted by the fault lines on the geological map.

Uniaxial Compressive Strengths (UCS) test results from fifteen EC2 samples taken from the better rock generally at between 40 and 50m depth saw values up to 53.13MPa and average strength of 28MPa suggesting the best rock strength is generally moderate to strong. The degree of discontinuities and the evidence from the rock core photographs indicates that a significant amount of lower strength rock is also present.

Point Load Index values $I_{s(50)}$ generally concur with the UCS testing when an appropriate conversion factor is employed. One high $I_{s(50)}$ test result was recorded suggesting that occasionally very strong rocks might be encountered.

The bedrock in all boreholes shows a high degree of weathering/fracturing in the upper elevations. Rock Quality Designation (RQD) is zero in the upper few to several meters of bedrock in each borehole. Furthermore, discontinuity differences indicate a high degree of folding and other compression impacts on the rock mass which has resulted in variable bedding angles of up to 85 degrees. Observation of the core photographs confirms that these results are predominately inherent features of the rock mass rather than core breakup during the drilling process.

At deeper elevations, generally the quality of the rock generally improves although there are still portions of some boreholes with very poor rock quality.

Petrographic tests were conducted on samples from the earlier 2013 boreholes and included an evaluation of mineral content. Quartz content of sedimentary rocks, especially sandstone, can be important when drilling due to the abrasiveness of the mineral. Typically quartz content in softer sandstone rocks should not be a concern for drill tool wear, however when rock quality is poor and the tools are required to undertake additional rotational work for additional pre-reaming and/or hole swabbing then monitoring of tool wear and employment of appropriate drilling mud management are important factors in ensuring success.

Faults - Dr MacCarthy's Report attempts to map this central section of the crossing and one version of his evaluation is shown here at Figure 19, an alternative interpretation is also provided in his report, though the differences in possible interpretation have limited impact on the drilling. Importantly his current interpretation is that one or two faults (F4 & F5) are present below the river and would be traversed during directional drilling. The materials within the faults may be more variable than would otherwise be the case elsewhere.

6.5. Monkstown

PGL Priority investigated the ground conditions at Monkstown. The Report for this work, “Cork Lower Harbour Main Drainage Scheme, Passage West & Monkstown Collection Network - Site Investigation - No. P13101”, dated 11/04/2014, has been reviewed. An interpretive report related to this study was also produced by PGL Priority and is dated 04/07/2014.

Reference to five PGL Priority boreholes in Monkstown has been made in this review (locations – Appendix B, Figure 18).

A borehole BH001-PM was sunk near Monkstown Sand Quay in the vicinity of the proposed tie-in structure (connecting the crossing to the Monkstown wastewater network) for the crossing. Also, borehole BH026-PM was sunk at Sand Quay.

BH001-PM encountered generally soft or very soft organic SILT with variable lesser amounts of sand and gravel to the full 12.5m depth of the borehole. No groundwater was encountered. SPT tests gave “N” values in the range 2 to 55, however the majority lie within the range 2 to 6. The highest values may be influenced by gravel and cobble presence in the upper 2.5m depth.

BH026-PM encountered sandy SILT or silty GRAVEL down to 15m depth (water strike at 14m in gravel rose to 3m in 20 minutes). SPT’s in the silt were all 5 or less and in the gravel rose above 50 at 15m depth. Coring below the gravel was in SANDSTONE interbedded with SILTSTONE. RQD’s were variable from 0 to 60 down to 30m total depth. The interface with the bedrock is recorded at -12.91m elevation.

Boreholes 031 through 033 were located within the playground car park and on the lower portion of Glen Road at Monkstown. These provide data relevant to the exit portion of the proposed drilling works.

BH031-PM at the Car Park (southerly side) had only 1.9m depth of SILT and GRAVEL with medium cobble content overburden above the reported bedrock elevation of +1.67m, which was categorised as being thinly bedded SILTSTONE with thin beds of sandstone. RQD’s were variable 19 to 77 down to 15m depth. Dip angle 40 to 60 degrees. UCS of tested sample at 11.8m depth was low at 16.47MPa. Tensile strength 1.35 MPa

BH032-PM, also at the car park, had 7m depth of overburden above the bedrock consisting of GRAVEL overlying sandy SILT overlying further GRAVEL with medium cobble content. Water encountered in the lower gravel rose to 2m depth in 20 mins suggesting the silt is fairly impervious. The silt has less than 10% clay and 60% sand. The bedrock below from -4.25m elevation was categorised as being SANDSTONE. RQD’s variable 0 to 71 down to 20m depth. Fractures dip 30 - 45 degrees.

BH033X-PM located on Glen Road had 5m depth of overburden above the rock consisting of GRAVEL with medium cobble content. Bedrock below from +2.7m elevation being MUDSTONE to 12m depth then SILTSTONE below to 15m depth. RQD’s variable 40 to 79 (plus a zero value at the bottom of the hole). Dip 50-70 degrees. Mudstone UCS 7.37MPa, Tensile 3.53 MPa.

The geophysical survey undertaken by Minerex Geophysics suggests that the bedrock possibly drops away in steps down the original alignment of the valley/water course alongside Glen Road and that in the vicinity of Sand Quay the bedrock elevation is at around -15mOD elevation, a little deeper than indicated by BH026. The overburden depth in BH's 031 and 033 suggest that the original width of the now infilled water course channel may have been quite narrow.

6.6. GROUNDWATER

Groundwater is not typically a major consideration in rock drilling, except that it is important to provide accurate data in the first instance to ensure the drilling contractor uses the correct drilling parameters and drilling mud mix. The marine boreholes were cased borings sunk below open water, furthermore when coring a water flush is employed, this masks the encountering of groundwater. These factors may be masking true water conditions within the superficial deposits and bedrock. Many borings report that groundwater was not encountered, however this may be misleading, especially as there was one report of "blowing" conditions in the gravel material in BH09-EC.

Packer tests undertaken in the bedrock give permeability values consistent with a highly fractured rock mass.

At Cobh, the presence of boulder clay reduces groundwater complexity.

The borings at Monkstown confirm that the granular GRAVEL material, lying generally above the bedrock across the whole site, is likely to be highly permeable and the overlying silt may retain an artesian pressure from this lower gravel level.

The bedrock is generally anticipated to present lower permeability, however highly fractured material may give up much more water readily when exposed.

Groundwater management would likely be more complex if the works were undertaken by tunnelling rather than drilling methods. Furthermore, groundwater management requirements at the Marine Villas interception structure will depend upon the methodology of shaft construction for these deep works and the permanent structure requirements.

6.7. GEOTECHNICAL SUMMARY

Consultant geologist Dr Ivor MacCarthy's report provides a very useful overview of the geology below the crossing taking into account the various land and marine site investigations that have been undertaken to date along with his observations of the outcropping geology in the vicinity of the project. A copy of Dr MacCarthy's current assessment of the geological mapping of the bedrock can be found at Appendix B, Figure 19.

Dr MacCarthy's Report Executive Summary explains what is now generally known about the site.

Some of Dr MacCarthy's key points relevant to the construction of the pipeline crossing include:

1. The anticipated bedrock is anticipated to be "*Late Devonian and Early Carboniferous sedimentary rocks (sandstones and mudstones) that have undergone low-grade metamorphism and extensive structural deformation."*
2. In addition to significant large-scale and small-scale parasitic folding of the bedrock *"There are up to three important NNW-SSE orientated sub-vertical faults intersecting the estuary crossing. The precise nature of these faults is not known. The bedrock also contains a number of other faults of varying scales."*

The presence of fault zones can impact directional drilling, especially where the structure of the rock is significantly different from other sections being drilled. There is an advantage to drillers if the location, extent and physical conditions of major faults can be defined, however this in practice is extremely difficult unless the general location of the faults is known and further investigation targeted.

Like the bedrock the superficial deposits which would be encountered in the early and final stages of directional drilling or during shaft construction for tunnelling and tie-in works are expected to be highly variable on both sides of the crossing.

At Cork Dockyard the granular deposits are indicated to contain gravel and cobbles. These may require stabilisation to ensure a drilled hole can remain open throughout the drilling process prior to pipe pull-in.

At Monkstown, the presence of soft silts within the possible infilled water course channel potentially make the design and construction of the tie-in structure more complex. Drilling operations at shallow elevation between Marine Villas and the Glen Road drill reception area may be more prone to inadvertent drilling mud returns where soft or loose superficial deposits are present. Potential design and construction mitigation measures for these and other potential risks are examined later in the report.

7. INSTALLATION METHOD OPTIONS

Four construction methodologies were initially considered for the crossing.

1. Dredging (open cut)
2. Tunnelling
3. Horizontal Directional Drilling (HDD)
4. Direct Pipe

Full technical description and methodology of these processes is included at Appendix C.

Due to space restrictions and the ground conditions the Direct Pipe method, a hybrid system combining tunnelling and directional drilling methods to install a steel casing, is not considered feasible for this crossing.

For this crossing, the environmental impact and pipe protection risk mean that a dredged solution is less desirable than trenchless solutions.

Due to the necessity to construct deep shafts at each end of a tunnel and that the final pipe system would need to be installed inside a primary lined larger diameter envelope, a horizontal tunnelled approach to the crossing is expected to be significantly more costly when compared with the directional drilling of two separate smaller bores. The construction and financial risks associated with tunnelling are at least equal to those of drilling through the geology envisaged.

Horizontal Directional Drilling (HDD) is applicable to this site due to its layout, subsurface conditions and diameter, and length requirements. A preliminary relative assessment of the probable cost for two pipelines installed by directional drilling established that this method is expected to be the most economical technically viable installation option.

A site selection study included an assessment of the available technologies using the Analytical Hierarchical Process. The AHP assessment concluded that the preferred methodology was HDD. As HDD is the most viable installation option it's feasibility in relation to the estuary crossing was assessed in further detail. The outcome of this assessment is described in the following sections.

8. ENVIRONMENTAL RISK AND MITIGATION

Horizontal Directional Drilling provides a methodology that immediately mitigates environmental risk by removing the majority of environmental interfaces typically seen with dredging works.

An environmental study was outside the remit of this report however it is recommended that, at detailed design stage, a Construction Environment Management Plan (CEMP) be undertaken by a suitably qualified environmental consultant and it is proposed that it would include the specific environmental risks identified on land and within the marine environment as well as any mitigation measures which may be required.

HDD operates from discrete working areas at each end of the crossing where containment and other environmental responsive procedures can be properly established, monitored and maintained. Excavations into the ground for HDD are therefore minimised and little if any material from these excavations needs to leave the site.

The process of HDD also minimises the requirements for soil disposal and material import. The diameter of the excavated bore being typically not more than 1.5 times the diameter of the pipe being installed. For these crossings each 500mm nominal external diameter force main pipe would be expected to require a bored diameter of between 600 and 750mm (24 to 30-inch) depending upon the contractors' largest ream diameter; this equates to between 280m^3 and 440m^3 of excavated material for each separate total bore length of around 1000m. This solid waste material, once separated from the drilling mud, is normally deposited in an approved landfill site. The solid waste material may also re-used as general fill, subject to meeting relevant environmental and construction standards.

While the methodology of HDD is designed to minimise environmental impact, when compared with other construction methods, there remain a number of specific environmental concerns peculiar to the process which need to be evaluated and mitigated as part of the design and construction of any project. These include:

1. Oils and fuel spillages
2. Inadvertent drilling fluid returns
3. Drilling fluid disposal

8.1. OILS AND FUEL SPILLAGES

The risk of oil spillages comes primarily from ruptured hydraulic hoses associated with the drilling rig operation. Mitigation measures include the contractor ensuring the equipment is in good working order and providing equipment and materials for any clean-up required. Static placed equipment should have drip trays below engines, fuelling points and tanks and the main hydraulic pumps associated with the drilling rig and other major components. Fuel spillage can be mitigated by ensuring all fuel oils are delivered to site and dispensed with appropriate equipment and processes. Small quantities of oils and greases are also used as part of the drilling process, especially for lubricating drilling components. Good site housekeeping is required to mitigate unnecessary wastage of these materials to the environment.

Where there is increased risk of contamination of water courses and hence risk to aquatic and/or marine life additional containment measures, equipment and procedures may be required locally to mitigate the increased risk of spillage contaminants reaching the water course and/or the marine environment.

8.2. INADVERTENT DRILLING FLUID RETURNS

Inadvertent drilling fluid returns are defined as those returns which occur somewhere other than the launch or reception sites at either end of the drilled bore. Inadvertent returns are a concern because bentonite based drilling fluids are used in significant quantities during the HDD process and these can have a negative impact on the environment, especially the aquatic and marine environment. Depending upon particulate dispersion level of the drilling fluid constituents (turbidity), especially bentonite clay, a reduction in the oxygen levels within the water can occur. If the particulate density is high it may lead to the suffocation of aquatic and marine life, especially in slow moving aquatic environments where the particulates have time to settle before full dispersion.

The Society of Petroleum Engineers and other oil and gas industry bodies have a large volume of information related to the use of drilling fluids and their environmental impacts on the environment and may assist in further evaluating the risks to the marine environment from the drilling operations.

To a much lesser extent the risk from inadvertent drilling mud returns may apply to invertebrate life and other fauna and flora at the surface where they occur on land in areas of vegetated ground cover.

Drilling mud additives, such as soda ash, polymers and detergents, which may form a small part of the mixed drilling fluid or are introduced at specific times during the drilling process, do not normally cause a material environmental concern unless mismanaged in their concentrated form.

Inadvertent drilling fluid returns can occur as a result of a number of reasons, all of which can be mitigated against although due to the nature of the work and the fact that drilling is undertaken through conditions that are not entirely definitively defined beforehand will result in some remaining risk. For this reason it is important to understand the site-specific risks and incorporate appropriate containment and clean-up plans accordingly.

The primary reason for inadvertent returns is as a result of poor conditions within the drilled bore. This may be as a result of:

a. Poor drilling methods,
b. Poor drilling mud formulation,
c. Issues with the stability of the bore in heavy granular soils or significantly fractured strata.
d. Insufficient bore depth (insufficient overburden)

These can all lead to normal returns to either end of the bore path being restricted or lost entirely and hence an increase in pressure of the drilling fluid in the bore, specifically at the drilling equipment in the hole, known as the Bottom Hole Assembly (BHA). If normal returns are not regained it may result in mud pressure being released outside the bore, such as to the surface or the ground, nearby underground infrastructure spaces, the bed of water courses, or marine environments.

The primary means of mitigation is through the use of appropriate drilling mud formulation and management for the conditions and appropriate drilling practices. For shallow sections, especially where these are unavoidable at the beginning and end of the bore, the emphasis is on appropriate drilling practices for the reduced overburden. Further mitigation can be achieved by continuous monitoring of the environment and the readiness of containment measures should a release occur.

Where the drilling designer considers the risk of inadvertent returns at the beginning or end of the bore to be unavoidably likely the risk to the environment can be further mitigated by casing the shallow section of the bore. The casing, typically a section of larger diameter steel pipe, is installed by a separate process. Typically this is installed from the surface along the alignment of the drilling. At Cork Dockyard a casing, if required by the contractor, would be installed from the surface along the alignment of the drilling. At Monkstown short casing could be installed from the surface along the line of the drilling or alternatively a casing could be tunnelled into place by microtunnelling from the interception shaft.

Should inadvertent returns occur from depth, the emphasis for environmental mitigation is focused upon clean-up and on an understanding of the dispersion processes in the marine environment. Dissipation of drilling mud release to the marine environment is highly dependent upon the currents and tidal movements in the harbour. An understanding of these movements would permit a marine specialist to evaluate the risk to specific marine life present.

The potential quantity of drilling mud released to the environment will primarily depend upon how quickly the release is observed and the drilling operation halted. If observation is swift the release may be very small, perhaps no more than a few cubic metres. In the marine environment the release may take longer to be seen at the surface and therefore the potential release of mud to the environment greater. Where the driller reports poor or lost circulation of the drilling fluid there will be an increased possibility of inadvertent returns until full circulation is regained and therefore observation and monitoring of the environment should be especially vigilant during any such periods.

Inadvertent returns at shallow elevations can be difficult to seal off and release at the location may continue on the recommencement of drilling. If this should occur the normal method of management is to create a small containment excavation and pump the fluid away for processing as it accumulates. In extreme cases the drill path might need to be modified, the section of bore hole sealed up (grouted) and redrilled, or the section cased.

At deep elevations special measures to halt leakage from the bore – beyond improving or modifying the drilling mud formulation, which is often sufficient – involve sealing the leakage path or paths with a special lost circulation materials. These materials are introduced as slugs into the drill pipe and pumped into the bore and are designed to clog the leakage pathways and allow the drilling mud to work properly again. Some of the possible lost circulation materials are not suitable for use in sensitive environments though others are. In extreme cases the bore may be grouted up and redrilled, or redrilled to a new alignment, to overcome the problem.

Although inadvertent returns can and do occur on some drilling projects industry best practice dictates that appropriate construction and contingency measures are always in place during the work to mitigate environmental or construction risk.

For the proposed crossing the greatest risks of inadvertent returns are likely to occur when the drilling is:

- Shallow – passing through weak and saturated soils with little inherent strength
- Shallow – passing through heavy granular material, ie gravel and cobbles, where bore stability may be more difficult to control
- Deep – If heavily fractured rock causes bore instability and a pre-existing pathway exists to allow drilling fluid to escape to the environment

The mitigation of these risks should be appropriately considered and managed within the programme of proposed works.

Mitigation measure may include:

- Casing of shallow portions of the route
- Pre-construction or during construction pressure grouting of identified unstable or highly fractured areas.
- Specialist drilling mud formulations and use
- Modified drilling processes, especially measures designed to maintain drilling mud returns

8.3. Drilling Fluid Management and Disposal

Bentonite based drilling fluid is mixed with water on site to gain full hydration. It is then stored in a tank or tanks (typically shipping container size) ready for use during drilling. Drilling mud containing cuttings retrieved from the bore are collected at the drill launch or reception sites and pumped or transferred to a mechanical mud separation plant, normally located close to the drilling rig or adjacent to the reception site (or both). Drilling mud remains in a closed circuit, either being stored within the holding tank, in use within the bore/drill pipe or being processed by the separation plant. Losses of drilling fluid from the surface set-up are negligible and do not normally have any environmental concerns provided normal site containment measures and protections are in place.

On completion of the works the drilling mud displaced by the product pipe insertion is processed to remove remaining cuttings in the normal way. This leaves the drilling mud itself requiring additional measures to process it down to its component parts. This may in part be achieved at site using a mixture or flocculating chemicals, fine filtering and centrifuges or the material may be taken off site by tanker for processing at an approved liquid waste facility elsewhere. Regardless of the methodology the final method of disposal needs to meet local and national environmental requirements.

8.4. Site-Specific Risks and Observations

In addition to the general environmental considerations of any site the following specific points are noted for this proposed crossing.

8.4.1. Water Course - Monkstown

The watercourse that runs alongside the play area and Glen Road in Monkstown is likely to be impacted by the HDD works. Access to the construction site will be required across it, mechanical equipment operating with fuel and other oils will be in close proximity to it and during drilling works any inadvertent returns of drilling fluid might create a risk of releasing drilling fluids to it; this risk is likely to increase as the bore approaches the drill reception site. This is a section of the proposed installation that might benefit from being cased unless the water course can be protected by other measures.

The contract documents for the drilling work should include appropriate language for managing the interaction with the water course including allowance for appropriate protection of it and the biodiversity present. Contingency plans should also be in place should contamination of the water course occur, including mitigating the risk of the contamination reaching the marine environment.

The water course may also need further protection along Glen Road if the road is used for pipe laydown.

8.4.2. Marine Environment

Provided the drill path below the marine environment is at sufficient depth and especially if undertaken through the underlying bedrock, then the environmental risks to the marine environment are considered to be minimal.

Some remaining work-related risk is present from land drainage run off via water courses or where drilling fluid inadvertent returns unexpectedly occurs through highly permeable or fractured strata to the river/estuary bed as discussed earlier.

8.4.3. Invasive Non-Native Species

During the initial site visit, what appeared to be Japanese Knotweed (Fallopia japonica) was noted. This is invasive non-native plant species that spread from the UK following introduction there as an ornamental garden plant in the mid-nineteenth century. It was noted during the site visit alongside the water course running up Glen Road.

A programme of invasive non-native species control is ongoing at a site to the rear of the play area at Glen Road, Monkstown and elsewhere along the Glen Road.

The *Irish Water Report, Information and Guidance Document on Japanese knotweed Asset Strategy and Sustainability,* provides information and management options for the control of Japanese Knotweed.

8.4.4. Excavations at Cork Dockyard

During recent ground investigations at Cork Dockyard hydrocarbon odour was noted in one of the borings. PGL Priority also undertook soil and groundwater sampling and undertook an environmental assessment (JMcH/ P13097A 21/03/2016) for the proposed launch site at Cork Dockyard. As might be anticipated for a dockyard environment some metallic and benzo(a)pyrene Contaminants of Concern (CoC's) were identified within soil/water samples, however ultimately they consider the risk of pathway to receptor linkages to be low to medium provided normal site health and safety procedures (ground gas risk assessment and mitigation etc.) and appropriate waste containment and disposal of excavated materials is employed during the works.

9. CONSTRUCTABILITY

The general discussion of the directional drilling process is provided under Appendix C. This section focusses upon the specific aspects in relation to utilising directional drilling for the proposed DN500 twin sewer mains crossing between Cork Dockyard and Monkstown.

HDD installation lengths of over 4km and diameters over DN1200 have been installed around the world over recent years. Installations are also regularly performed through rock strata. The installation length required for this project is a little more than 1km and the diameter DN500 which places the crossing well within the capacity and capability of specialist international large (maxi) HDD contractors. Table 1 lists a selection of European and international drilling projects which have been completed in the last few years and share similarities with this project in terms of the level of complexity, location and condition.

While lengths over 1km could be contemplated for this project, if other drilling and receiving sites were utilized, there would likely be implications for pipe material selection and the methods of working which would increase the complexity, risk and cost of the crossing. Lengths above 1.5km would represent a significant increase in the complexity of the works.

Table 1 - Recent Project Examples

Project	Location	Year	Length	Diameter	Geology
Pembroke gas pipeline	Milford Haven, UK	2010	3000m	457mm	Rock
Chonais Hydro Power Project	Wester Ross, Scotland	2014	1150m	705mm	Rock
North courier pipeline	Athabasca River, Alberta Canada	2016	2195m	1076mm	Rock
Lake Oswego Tigard Water Partnership	Willamette River, Oregon, USA	2014	1189m	914mm	Rock
Oyster 2 wave energy project	Orkney, Scotland	2011	600m	559mm	Rock
WWTW Outfall Ribeira / La Coruña	Spain	2015	447m	560mm	Rock

9.1. HDD Working Areas and Pipe Laydown

9.1.1. Working Areas

The size of operation required for the crossing requires that considerable space be afforded to the drilling contractor for their operations, especially at the launch site side of the bore. In addition to the drilling rig, space is required for drill pipe storage, drilling mud material processing, and management and support facilities such as steering system operation, workshop facilities and space for electrical power generation.

Directional drilling operations on projects of this nature are normally undertaken on a 24-hour, 7 day per week basis. This is to limit the time the bore is open before the pipe is installed, to help maintain mud flow and function within the bore and manage bore stability. A key consideration is the inevitable noise and local disruption that will occur during the work, especially at night and during weekends. Noise is generated by the power generation equipment, the pumps associated with the drilling rig and the noise generated by the solids separations system. While these systems generally are typically lower noise emitting items than conventional construction plant, noise generated at night, even at low levels below permitted values inevitably causes local nuisance. A detailed noise assessment of the proposed launch and reception sites has been carried out. This assessment established appropriate noise and vibration limits and mitigation measures that would permit the proposed HDD works to proceed were recommended, including housing of certain equipment at the reception site and installation of noise barriers at the launch site. The report will be included in the Cobh 146B Planning Application to An Bord Pleanala.

Each pipe-pull occurs in a single continuous operation that typically lasts no more than 24 hours but can be longer. The pull-in process should not be disrupted unnecessarily due to the risk of seizing the pipe in the borehole. In some circumstances short stoppages to connect and test an additional section of pipeline is required, though best avoided when possible. The Contractor needs to be able to rely upon free access to the works and pipe laydown area during the pullback periods.

At Cork Dockyard, there is currently ample open area and excellent vehicular access to support a drilling operation. A working area of at least 2500m^2 should be considered as a minimum for contractors operations.

Figure 4 – Cork Dockyard – Proposed Pump Station and works area centre rear.

At the reception site, where the pipe would also typically be introduced into the ground, space is required for support activities at the reception site including possibly, depending on the contractors preferred methods, a second smaller drilling rig to support the operation and the management of drilling mud produced during the reaming operations.

The proposed reception site at Monkstown is adjacent to a play area alongside Glen Road. Maintaining access to the play area during the works is an unreasonable and restrictive requirement which any contractor would find difficulty in meeting. A temporary bridge over, or culverting of, the water course alongside Glenbrook will be required in order that full site access can be gained to the west of the play area.

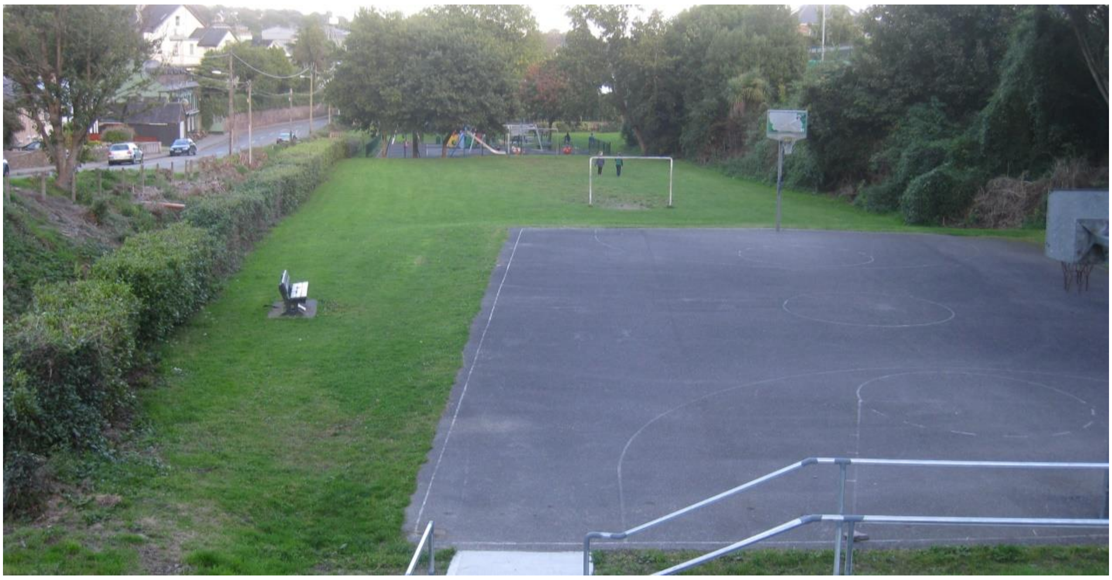

Figure 5 - Proposed drill exit point - adjacent to Glen Road.

9.1.2. Pipe Laydown

The principal space requirement on the reception site is that required for stringing-out the product pipelines prior to pull back into the prepared bore. A linear space is traditionally required running roughly in-line with and beyond the reception site drill exit point for the full length of the bore. This enables the contractor to fabricate the full length of pipe required from shorter sections, butt fused together (in the case of HDPE pipe) on site. Fusing operations are typically undertaken at a static facility with the pipe positioned on rollers to permit ease of movement of the pipe string and minimising the risk of damage.

The length of time the contractor needs for the pipe laydown area depends upon the time required to fuse and test the pipeline, any delay after fabrication before the pipe can be pulled in and the duration of the pull-in and clean-up operations. For a long pipeline this may be several weeks.

It is expected that the pipe will be prepared offsite or even supplied to site as a continuous length, in which case the pipe can be moved from the temporary location to the designated pipe laydown area just prior to pull-in.

The pipe is set on rollers to eliminate the risk of damage during pull-in.

Figure 6 - Pipe laydown example (Image A E Yates)

Neither Monkstown nor Cobh has readily available unrestricted areas sufficient to string out and manage in excess of 1000m of pipeline.

At Cork Dockyard there is no readily available pipe laydown route option behind the proposed drilling point therefore pipe laydown will need to be facilitated along Glen Road, Monkstown and the primary directional drilling site and launch site shall be located at Cork Dockyard.

At Monkstown, the west side of Glen Road is the logical laydown route for either the full length of the pipeline in one piece or in two or three parts if the space available to the contractor is necessarily restricted.

From the junction with Hazeldene Court northwest along Glen Road for approximately 150m the road and southwest verge width to the boundary wall provides sufficient width for maintaining access for local residents of the adjacent houses while the works are ongoing. During the pull-in operation, which would typically last up to 24 hours, access to the adjacent properties may need to be by foot only.

Beyond this point and continuing northwest to Diamond Road, Glen Road narrows to a width generally of around 4m and has no adjacent property accesses. The road width, along with any available additional flat space within the verge on the south west side, affords sufficient space for pipe stringing but is unlikely to be suitable for public access at the same time, therefore the use of this section by the contractor may need to be restricted to the minimum duration possible. Utilising continuously extruded pipe would greatly reduce the time required for the road to be closed to the public. Two separate closure periods would be required in order to complete the two separate pipe installations.

Part way along this section towards the junction with Scotchman's Road, there is a bend. At this location an anchor block may be required to restrain the pipe to its roller path around the bend.

North of Scotchman's Road the road width is a little wider at generally 5m, however the periodic accesses on either side of the road make staging the pipe more awkward but certainly possible. The pipe would need to be staged on the east side initially then transfer to the west alongside the golf course. This will then enable vehicle access to the adjacent properties to be maintained from either end.

At the end of the pipe laydown area sufficient space is required for winching equipment. Glen Road rises gradually in elevation from a little above sea level to around 85m AOD at the end of the full pipe laydown length. The pipe will need to be hauled up and restrained using a winch or other means from the highest point prior to pull-in and to assist in control of the pipe during pull-in operations, especially if the pipe is ballasted with water to make it neutrally buoyant within the drilled bore. Sufficient space is needed for the winching equipment and the water supply, typically a tanker, therefore some access restrictions may be necessary while the pull-in process is underway. At other times access to the adjacent properties should be maintainable if the pipe is staged along the edge of the road and the adjacent verge.

If the full length of the pipe is staged the winch would be located alongside the Golf course. Alternatively, if the pipe is staged in two or more sections the logical location for the winch and support operations would be between Diamond Road and Scotchman's Road. Glen Road is wider at this location at around 6m with good access from the connecting roads.

Staging of the full length of pipeline would impact the Scotchman's/Glen junction with access to these roads required from their opposite ends. Access to Scotchmans Road and Diamond Road from Glen Road would need to remain closed until the pipe has been pulled up.

The equipment associated with winching and ballasting is required in operation for a short duration only. Power generation can be super silenced and the other items generate negligible noise. This area of activity is not therefore normally sensitive with respect to noise generation.


Figure 7 - Glen Road looking northwest

9.2. Diameter Of Bores

HDPE diameter is defined by the external diameter and the wall thickness; therefore the internal diameter will vary depending upon the HDPE DR selected. The specification for the pipe size needs to take into account the hydraulic performance requirements. It is anticipated that two 500mm diameter HDPE pipes will be required for the crossing.

Assuming that the reamed diameter is up to 1.5 times the pipe diameter, the maximum reamed bore diameter might be expected to be 750mm (30-inch) for a single pipe.

If both mains are placed within a single bore the minimum internal diameter would be expected to be around 1500mm, exceeding the diameter realistically practicable by HDD. Twin pipes within a single crossing conduit would only be possible with Direct Pipe or conventional tunnelling methods, both of which have been discounted for this project.

9.3. HDD Bore Alignment & Profile

The actual drill alignment and profile, including the drill entry angle, vertical and horizontal curve radii, general or maximum running depth, and drill exit configuration are normally established as part of the Contractor's design. It is however normal to set some basic performance and limitation criteria within the contract drawings and specifications, especially where they relate to the performance of the final product or to meet specific regulations or agreements with third parties.

With respect to the drill profile and alignment for this crossing it is considered necessary or desirable to consider:

1. Intersection of defined points at Cork Dockyard and Monkstown to enable connection of the pipes to the rest of the system, including the proximity of adjacent bores
2. Horizontal pipe spacing at the intersection points and any restrictions (maximum and minimum) to be imposed on spacing below the river. A minimum spacing of 5m is recommended.
3. Maximising drill & pipe radii to limit construction loads and reduce risk
4. Minimising drilling length through less stable gravel strata, including gravel containing larger granular material (cobbles), and areas of highly fractured rock
5. For hydraulic purposes a desired single lowest point
6. Minimising risk of negative environmental impact from inadvertent returns

9.3.1. Drill Entry/Exit & Construction Interfaces

It is understood that the contract for the crossing will be separated from the contract(s) for other works. As a result there will be potential interface requirements with other contractors and constructed works during the approximately six months of work required to complete the two pipeline crossings.

Due to the space required at the Cork Dockyard launch site it is recommended that the drilling contractor have full utilisation of the space before other works are constructed. The tie-in positions for each crossing pipe (horizontal and vertical) must take into account any positional accuracy tolerance specified for the drilling operations.

The drill entry angle is typically around 10 degrees. A low angle of entry reduces the complexity of pipe tie-in operations and improves the safety for operatives working on the drilling rig. Steeper drill entry angles permit the drilling operation to passage quickly through poorer quality superficial deposits where there is increased risk from drilling fluid breakout (inadvertent returns) or bore collapse, though this risk can also be reduced by other measures applied locally, e.g. by casing the bore through the poor geology. Increasing the drill entry angle also reduces the length of ground sterilisation above the bores. Most drilling rigs can accommodate drill entry angles between 5 and 18 degrees.

Drilling at an entry angle which exceeds the normal maximum for the equipment would require special measures; this would likely increase cost.

At Cork Dockyard the overburden above the bedrock is of limited depth and consists primarily of granular sandy gravel with cobbles potentially overlying gravelly boulder clay. It is likely that contractors will prefer to traverse the granular strata as quickly as possible and therefore they may prefer a steeper drill entry angle.

As the actual drill entry angle is normally established by the contractor it is advisable if possible to construct any tie-in structures after the crossing pipes have been installed. It is proposed to tie-in to the Monkstown wastewater network at an interception manhole at Marine Villas, adjacent to Sand Quay. For the drilling contract a desired but flexible intersection alignment and elevation, along with an appropriate tolerance, might be set. Setting a defined depth for the crossing pipe at the tie-in points may induce a restriction on the contractors preferred drill entry angle and therefore if possible a depth range would be preferable.

At Monkstown the preliminary design has an invert elevation at the proposed tie-in structure at Marine Villas (Figure 8) of -15mOD (Figure 14). The location of this structure is approximately 170m east of the proposed reception site adjacent to Glen Road. The ground elevation at the reception site is around +5m elevation. This configuration results in a likely drill exit angle of around 6 degrees, being in the normal range for drilling operations and in good alignment with the pipe pull-in alignment from Glen Road.

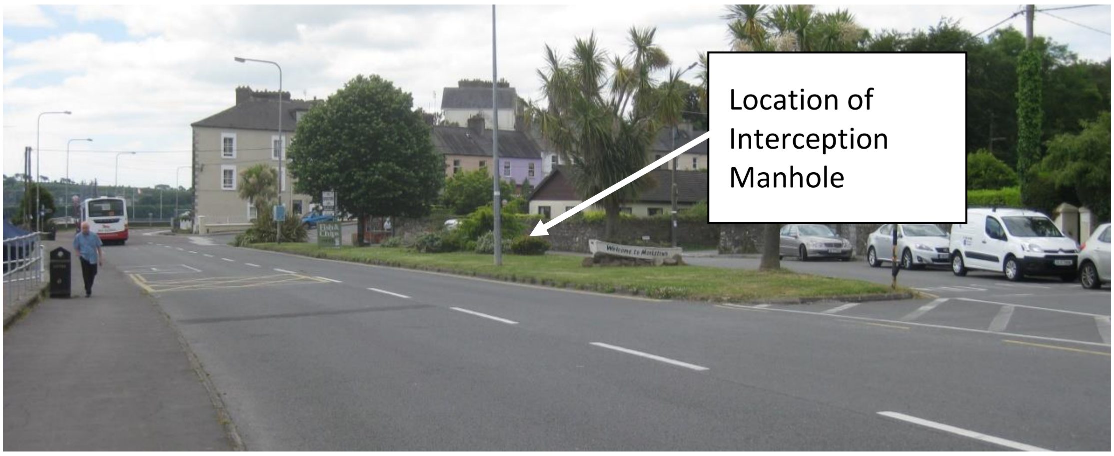

Figure 8 - Proposed location for interception manhole at Marine Villas

Regardless of the above the exit section is inevitably at decreasing depth and therefore:

a. There is increased risk of inadvertent drilling mud returns to the water course running alongside Glen Road and/or the low lying gardens above the route (Figure 9).
b. Ground conditions through this section includes low strength silts and infill material possibly associated with the original water course channel.

Figure 9 - Water course and low lying gardens adjacent to Glen Road

For the above reasons consideration should be given to casing the section of the bore between the Glen Road temporary reception site and Marine Villas interception manhole. The casing would act as an independent support to the ground and provide a containment structure for drilling operations. The casing would be installed either by a drilling and forward reaming operation undertaken from the reception site or a microtunnelling/pipe jacking process undertaken from the proposed interception manhole at Marine Villas, Monkstown.

9.3.2. Curve Radii

Bores are typically steered straight for a short distance before any steering to a planned curve is undertaken. Steerage of a vertical curve is normally undertaken first to take the drill path down to the proposed principal installation depth. Horizontal steerage for horizontal curves is not normally undertaken at the same time as vertical curve steerage though with the most modern monitoring equipment and good operation steerage in both planes simultaneously is certainly possible and may be required for the exit phase of this crossing.

Curve radii should be the maximum possible for the required configuration. Although curve radii down to 200m may be technically possible for a mud-motor driven pilot hole it is not recommended that curve radii of less than 500m are employed to minimise loads during pipe pull-in.

A straight horizontal alignment is possible between Cork Dockyard and the Marine Villas tie-in structure, however in order to reach the reception site adjacent to Glen Road a rotation of between 3 and 4 degrees is required. To avoid the necessity to steer horizontally within the final section, especially should this final section be cased, the horizontal curve would best be considered below the River Lee prior to any vertical curve commencing toward Sand Quay. This requires the entry angle at Cork Dockyard to be rotated by around 2 degrees towards the north.

The near straight alignment for the crossing afforded by utilising Cork Dockyard considerably reduces the risks during drilling and pipe pull-back.

9.3.3. VERTICAL PROFILE

The proposed drilling site at Cork Dockyard has a drill entry elevation circa +3m and a proposed invert elevation leaving the pump station of around -3m to -4m elevation. Meeting the required invert elevation may require the contractor to exceed the preferred maximum drill entry angle unless the drilling rig can be set sufficiently back from the proposed pumping station and therefore some flexibility in the elevation permitted should, if practicable, be considered.

Bore depth, as well as the general arrangement for the horizontal and vertical profile, is typically selected and developed by the contractor and based upon the ground conditions anticipated and any specific prescriptive limitations or performance requirements.

The gravel and other granular materials indicated to be present generally directly above the bedrock, the presence of very soft silt in the overburden, which may limit drilling mud containment capability and the need to mitigate the possibility of inadvertent returns, in combination push the logical installation deeper into the underlying bedrock.

We understand that for the best performance of the proposed pipeline a single low point is preferred. This would be achieved closer to the Cobh side of the crossing with then a shallow angle rise towards the west.

Assuming the installation within the bedrock then a maximum installation elevation below -37m elevation is required, being the apparent lowest interface with rock in the centre of the river. This might be increased to -50mOD elevation if the most fractured bedrock is to be avoided. Raising the elevation of the bores would increase the risk of encountering poor quality rock and/or gravel and cobble material.

9.3.4. INSTALLATION ACCURACY

In order to intersect with proposed structures and provide the required operational performance the crossing requires a high degree of installation control. Steerage of the pilot hole BHA relies upon the drill operator having a good understanding of the position and orientation of the BHA from one drill pipe joint to the next. For this reason it is recommended that an optical gyroscopic steering tool be deployed during pilot hole drilling. The reporting accuracy of these tools is typically around 0.04^{o} horizontally and 0.02^{o} vertically, which equates to around +/-700mm and +/-350mm respectively for a 1km long crossing length. The tie in structures, at around 830m along the drill path will need to accommodate these working ranges as well as a reasonable tolerance for the drill operator. At minimum a 1000mm horizontal and 500mm vertical installation tolerance should be considered with respect to the impact upon the design.

9.3.5. Drilling Mud Management

During the pre-reaming phases when the bore is being opened up in stages to its required diameter the majority of the pumped drilling fluid containing cuttings from the bore will normally exit the borehole at the reception/pipe side of the crossing at Monkstown. This cuttings laden mud needs to either be processed at this site or transferred back to Cork Dockyard for processing. Even if the material is processed in Monkstown the clean drilling mud still needs to be transferred back to Cork Dockyard for reuse.

One of the simplest methods of return is to utilise a second pilot hole to transfer mud from Monkstown to Cobh. As two pipelines are required the initial drilling of both pilot holes is a logical option. Once one bore is complete with the HDPE pipe installed, a temporary internal pipe inside the new HDPE pipe might be used to transmit drilling mud back during the pre-reaming of the second bore.

The alternative approach open to the contractor is to tanker the material from Monkstown to Cork Dockyard via the highway.

The ultimate decision is normally left with the contractor and therefore any restrictions or performance requirements should be considered within the Contract documentation.

10. CONDUIT MATERIALS

High Density Polyethylene (HDPE) is the envisaged material for the proposed pressure pipelines.

The HDPE DR class (wall thickness) for HDD installation would typically be determined by the contractor based upon envisaged and calculated pullback load requirements, this typically being the dominant design parameter, in addition to the operational and other installation loads and pressures. A maximum DR may be specified to provide a minimal level of expectation. It is not recommended for a crossing of this type that the DR is greater than 11.

HDPE pipe sections would be fusion welded prior to pull-in to form a continuous string. Welding would either be performed on site within the pipe laydown area provided or alternatively longer sections of pipe might be jointed and tested off site, perhaps within the harbour area, and floated to Monkstown after fabrication. For example, section lengths of at least 200m and possibly even 500m might be achievable if additional space at Cork Dockyard is afforded to the contractor.

Figure 10 – Cork Dockyard & Commercial Area

If local off-site fabrication facilities are unavailable or unsuitable, pipe may if desired be procured and delivered direct to site from specialist suppliers such as PipeLife in Norway. PipeLife Norge AS can continuously extrude HDPE in standard lengths of up to around 550m and up to 850m as a special. These are then towed to site by sea and locally stored if necessary prior to use. PipeLife have previously supplied continuously extruded HDPE to the City of Cork (2001).

There is a significant benefit in reducing community disruption if fabrication and testing of the pipe string (or sections of pipe string) is undertaken off site. It also offers better opportunities to manage quality control of the fusion jointing operations. A continuously extruded pipe, such as that produced by PipeLife that has no joints within the extruded length has potential long term quality benefits.

Figure 11 - PipeLife extrusion facility, Norway

During pipe pullback careful management of the pipe buoyancy will be required. Pipe buoyancy (or weight) if not neutrally managed can have a significant impact on friction within the bore and hence the pullback load required. For an HDPE pipe the normal method of weighting the pipe is to fill it with water, in a controlled manner, to eliminate air.

11. RISK PROFILE

All trenchless underground works carry inherent risk, primarily due to the inability to visualise the conditions metre by metre, this means that planning must all be undertaken up front before any excavation into the ground is undertaken.

Risk can be mitigated by paying special attention to the selection of the experienced contractor, the detailed design and specification of the work, meticulous pre planning of all elements of the construction phases and the evaluation, and implementation, of contingency measures for remaining risks identified.

Table 2 provides a risk and risk mitigation overview of the preliminary crossing proposal between Cork Dockyard and Monkstown.

Crossing Delivery Risk	Probability	Consequence	Mitigation	Residual risk
Crossing design complexity	MEDIUM	HIGH	Design to Eliminate reverse curves & minimize length and diameter to within experience level	LOW
Crossing construction complexity	HIGH	HIGH	Careful selection of drilling contractor based on prior experience. Detailed design oversight and scrutiny	LOW
Fractured, bedded and steeply dipping geology with the added complication of fault zones and gravel with cobbles overlying rock. Softer silts in upper elevation at Monkstown.	HIGH	HIGH	Keep to deeper better geology and avoid larger granular materials and softer silts where possible.	MEDIUM
Manufacture pipe string in long sections off site or procure continuously extruded pipe from PipeLife.	HIGH	MEDIUM	Utilise attenuated equipment where available. Minimize night time activities. Provide acoustic barriers where required. Dust suppression processes introduced.	LOW
Environmental - surface run-off	HIGH	HIGH	Materials containment management at each working area.	LOW
Environmental - Inadvertent drilling return to watercourse/foreshore/river or private property.	MEDIUM	HIGH	Consider need for casing of shallow vulnerable sections, especially through poor superficial deposits. Place main installation at the most appropriate elevation through the best geology to minimise borehole instability and fluid migration risk.	LOW
Environmental - Invasive species (Japanese Knotweed - Monkstown)	HIGH	MEDIUM	Containment and Management with local partners	LOW
Environmental - Noise from construction activities	HIGH	MEDIUM	Sound attenuation measures including acoustic enclosures and sound barriers. Minimise unnecessary works outside normal working hours.	LOW
Pipe Laydown space limitations	MEDIUM	MEDIUM	Manufacture pipe string in long sections off site or procure continuously extruded pipe.	LOW
Accesses - Community impact	MEDIUM	MEDIUM	Work with community to positively minimise conflicts through appropriate traffic management and contractor access regime.	LOW

Table 2 - Risk Profile and Mitigation

12. CONTRACTUAL MEASURES

Assuming contractors are prequalified on the basis of relevant prior experience in similar conditions and experience of the proposed contractor's staff, then the most important process to be undertaken is for all parties to be satisfied that all the detailed design has been scrutinised and the planning proposals rigorously tested prior to drilling commencing.

Some specific prescriptive elements of the works specification will need to be provided to the contractor, these are best limited to areas that relate to the product to be installed and any local, national or international standards or restrictions to be applied.

For all other requirements a performance based specification will ensure that the contractor is focused upon performance of all elements of the work, including design inputs, planning, safety, quality and programme and dealing with any special challenges that come up during the work.

Interrogation of contractors' proposals can be undertaken in two phases, firstly at the time of tender, facilitated through contractor interviews, and secondly through review of the detailed work package plans, risk register development, and monitoring of the quality programme.

A number of industry resources are available when considering best practice and specific points, prescribed or performance based, which might be consulted when developing the contractual package. Some examples include:

- ASTM F1962; Standard Guide for use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit Under Obstacles, including River Crossings (2011).
- HDD Consortium; Horizontal Directional Drilling (HDD) Good Practice Guidelines (2008)
- Plastics Pipe Institute; Handbook of polyethylene pipe - second edition. Chapters 3 & 12.

An emphasis during construction should be placed upon the recording and preservation of records from all elements of the works, including drilling operations for all phases, alignment control during the pilot bore(s), and drilling mud preparation and management. Data should be collated by the contractor and provided as a record to the other parties together with the written daily reports from the drilling operations team, site supervision team and any other relevant parties. These records form the basis of the quality control and assurance process and are invaluable in evaluating and responding to issues or disputes.

Sampling of the material removed from the bore during the pilot drilling and reaming phases can assist geologists in understanding the materials that the bore is passing through though it should be acknowledged that the destructive nature of the drilling operations means that detailed analysis, if required, can be difficult and costly.

APPENDIX A

HISTORICAL MAPS

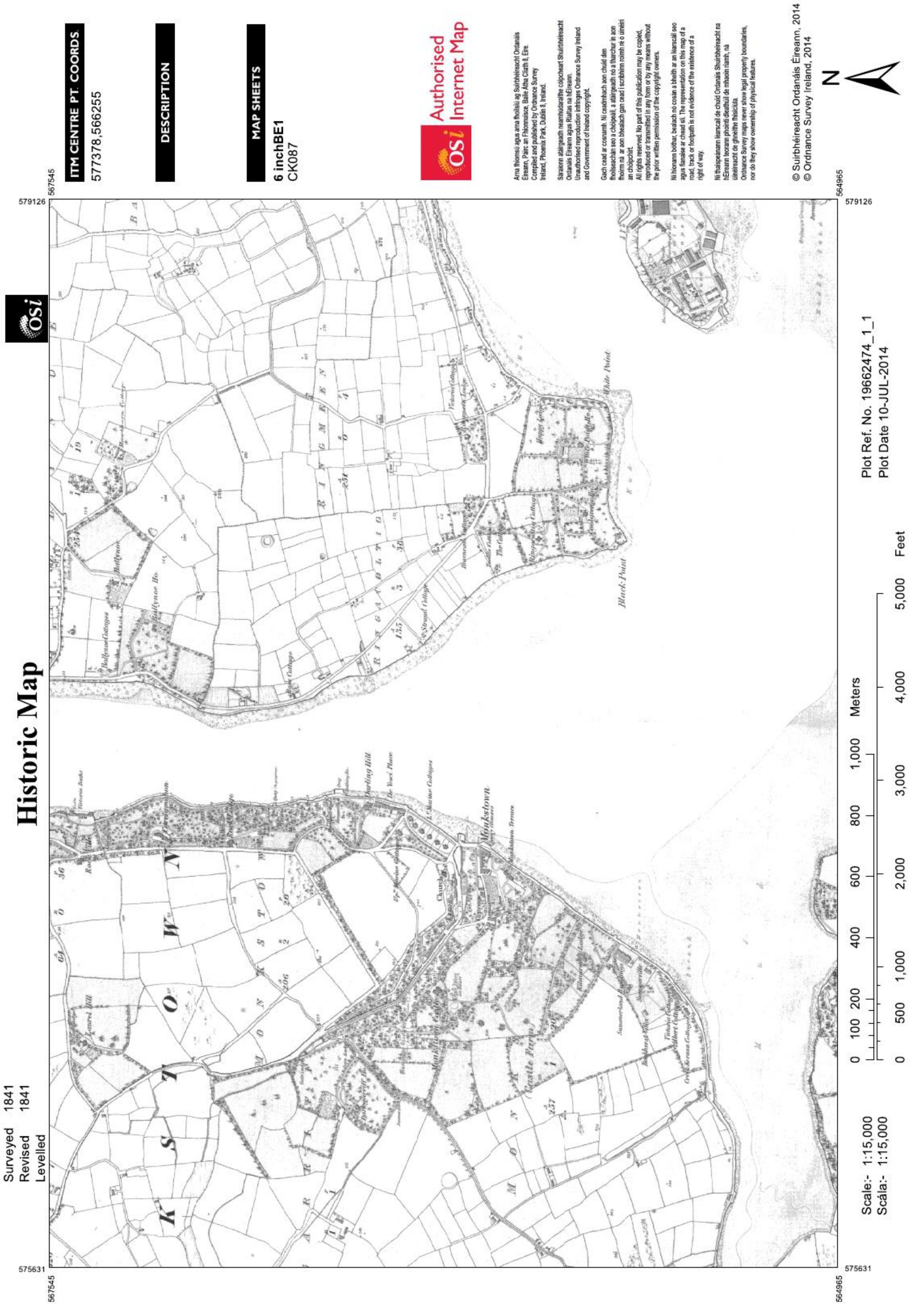

Figure 12 - 1841 Map – River Lee – Monkstown & Ringacoltig

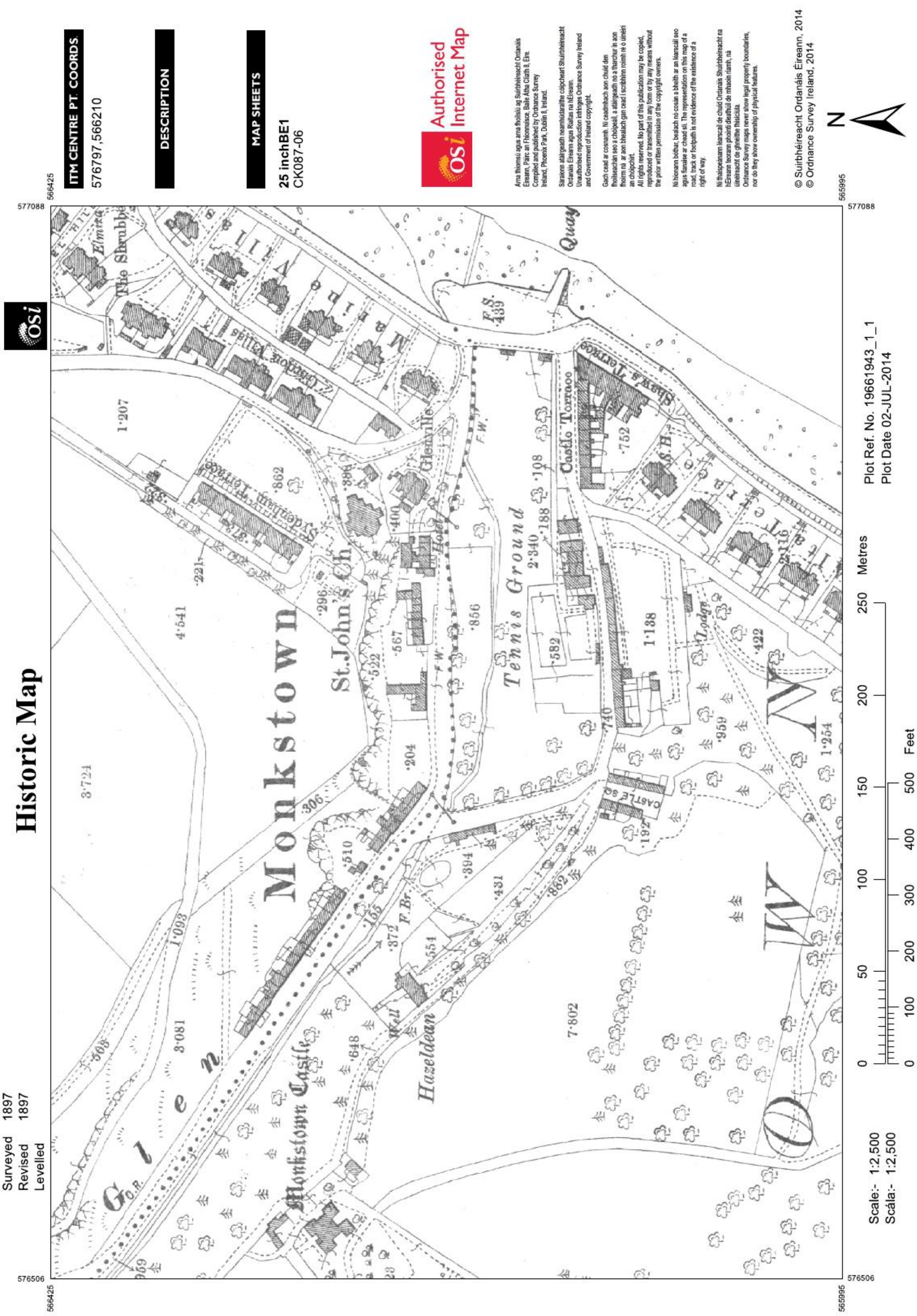

Figure 13 - 1897 Map - Monkstown

APPENDIX B

DRAWINGS

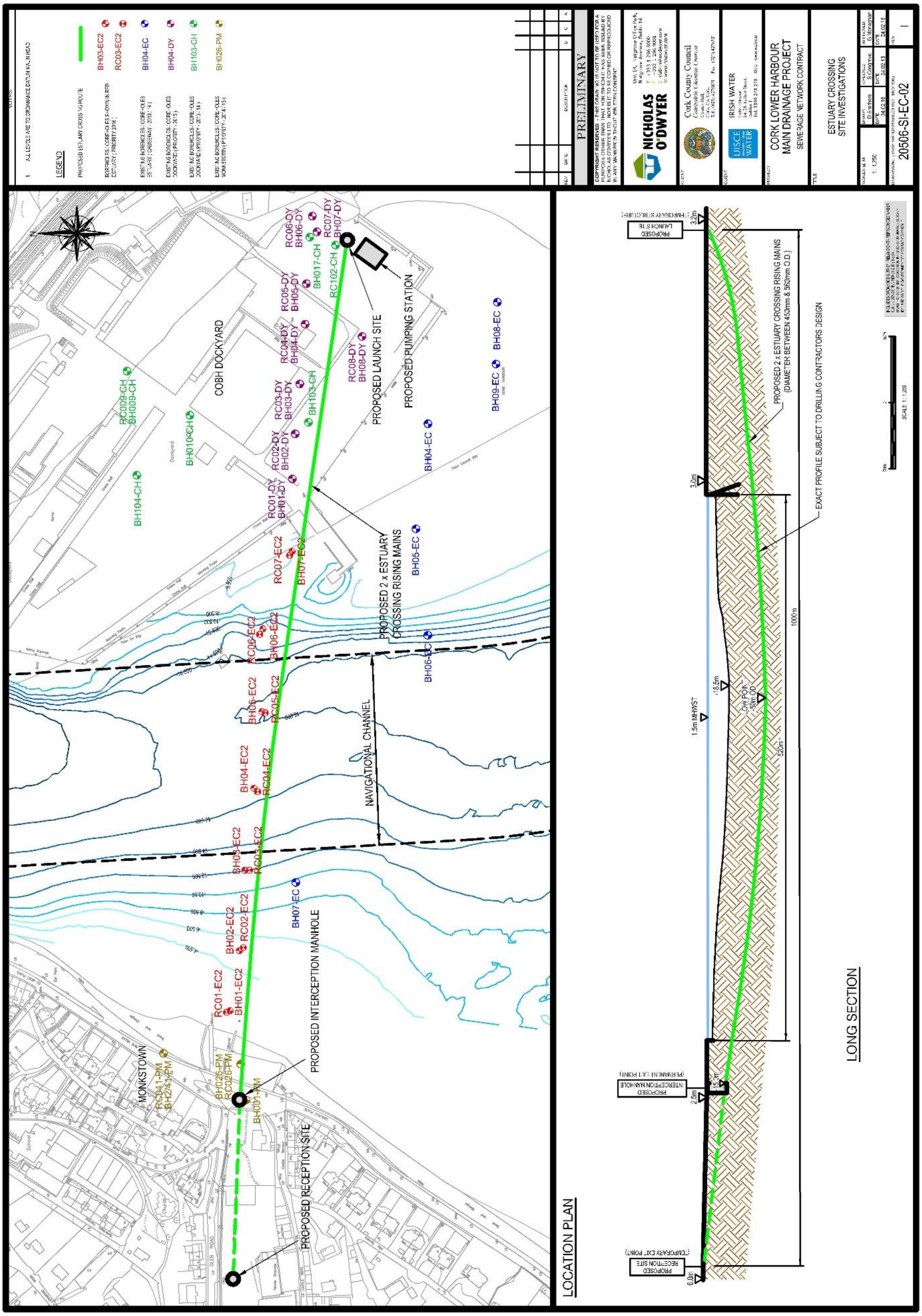

Figure 14 - General Arrangement of proposed crossing including recent subsurface boring locations

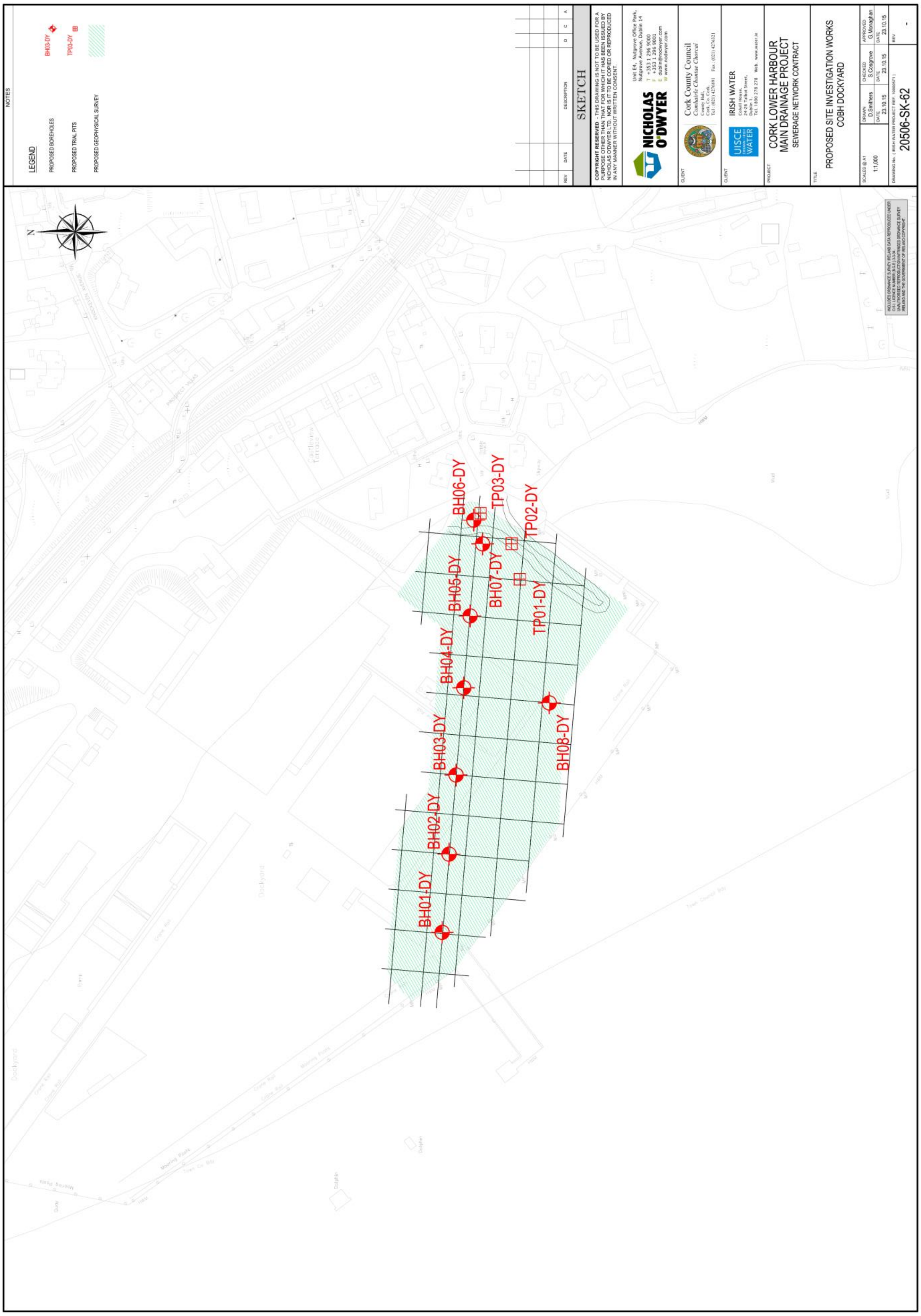

Figure 15 – Cork Dockyard "DY" Boring locations

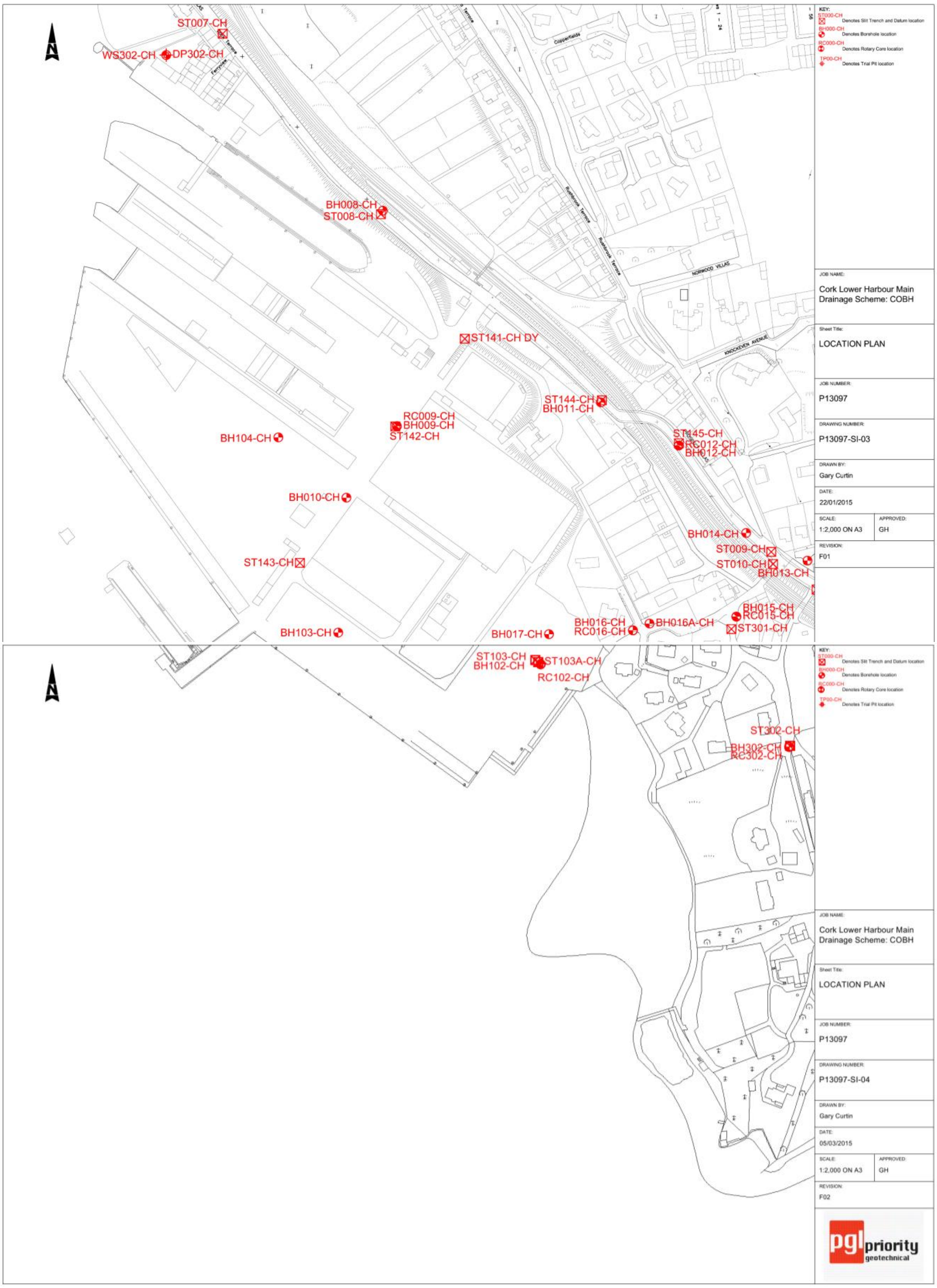

Figure 16 - 2013 Boreholes at Cobh

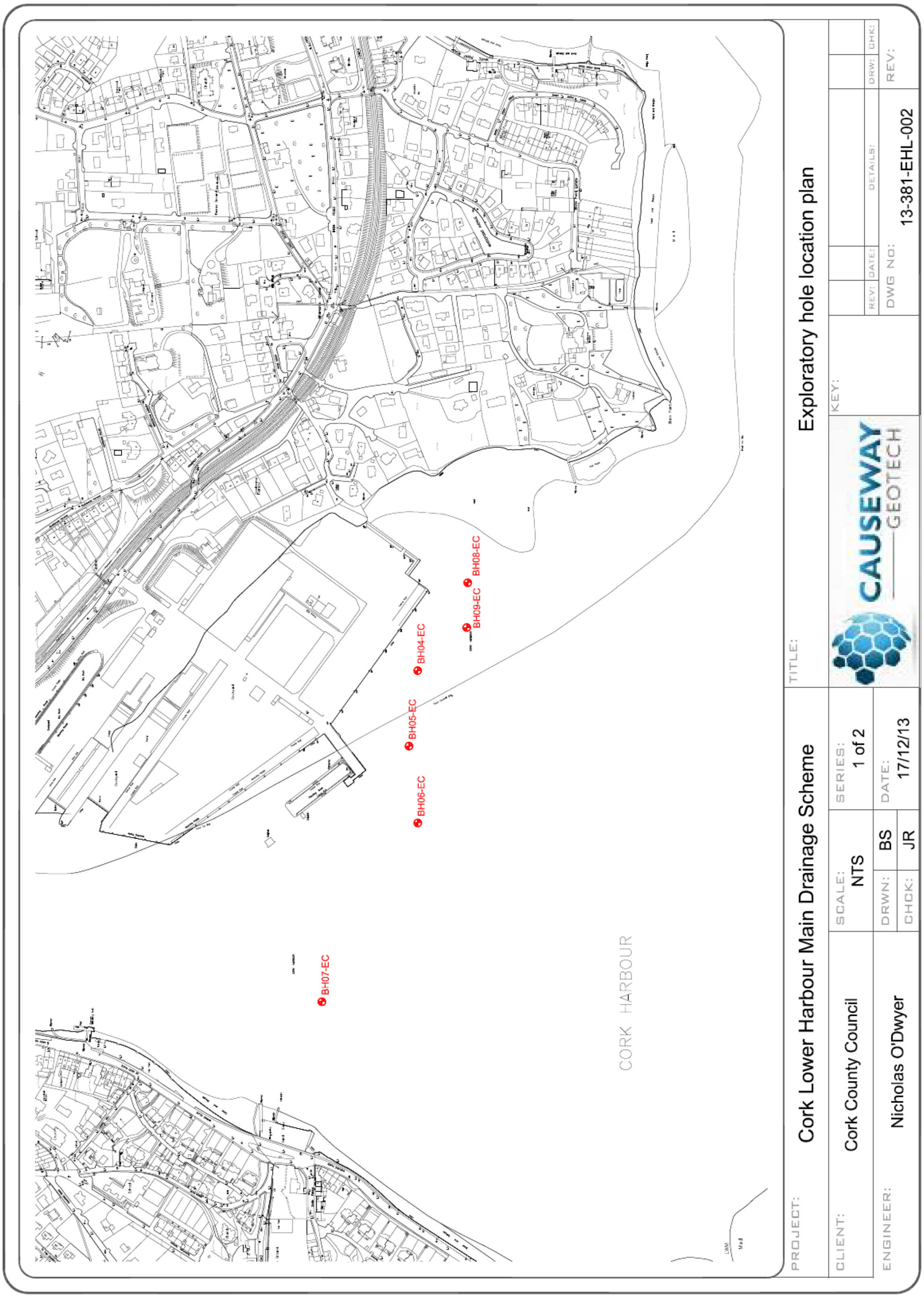

Figure 17 - Original Marine Boreholes

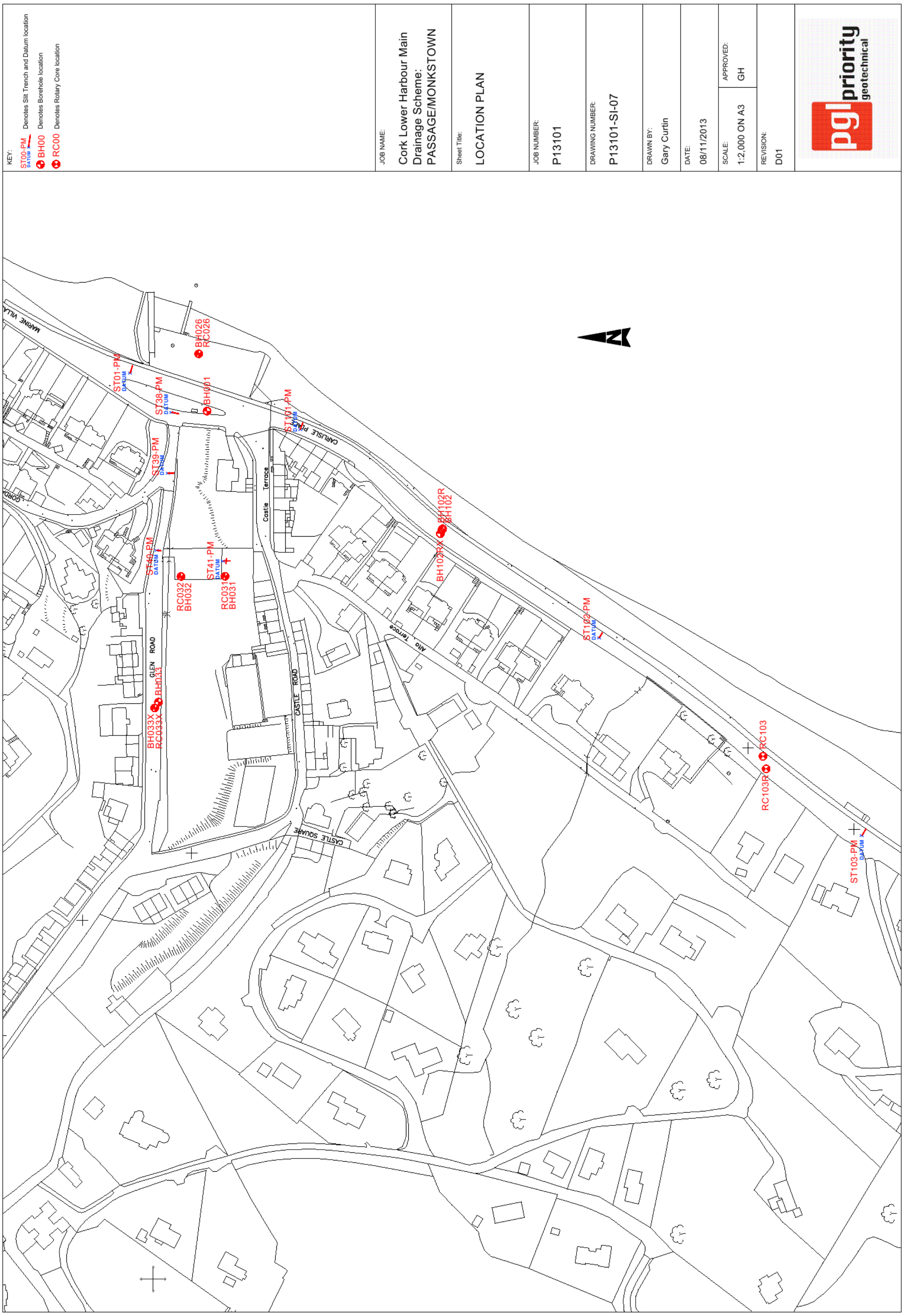

Figure 18 - Borehole Locations – Monkstown

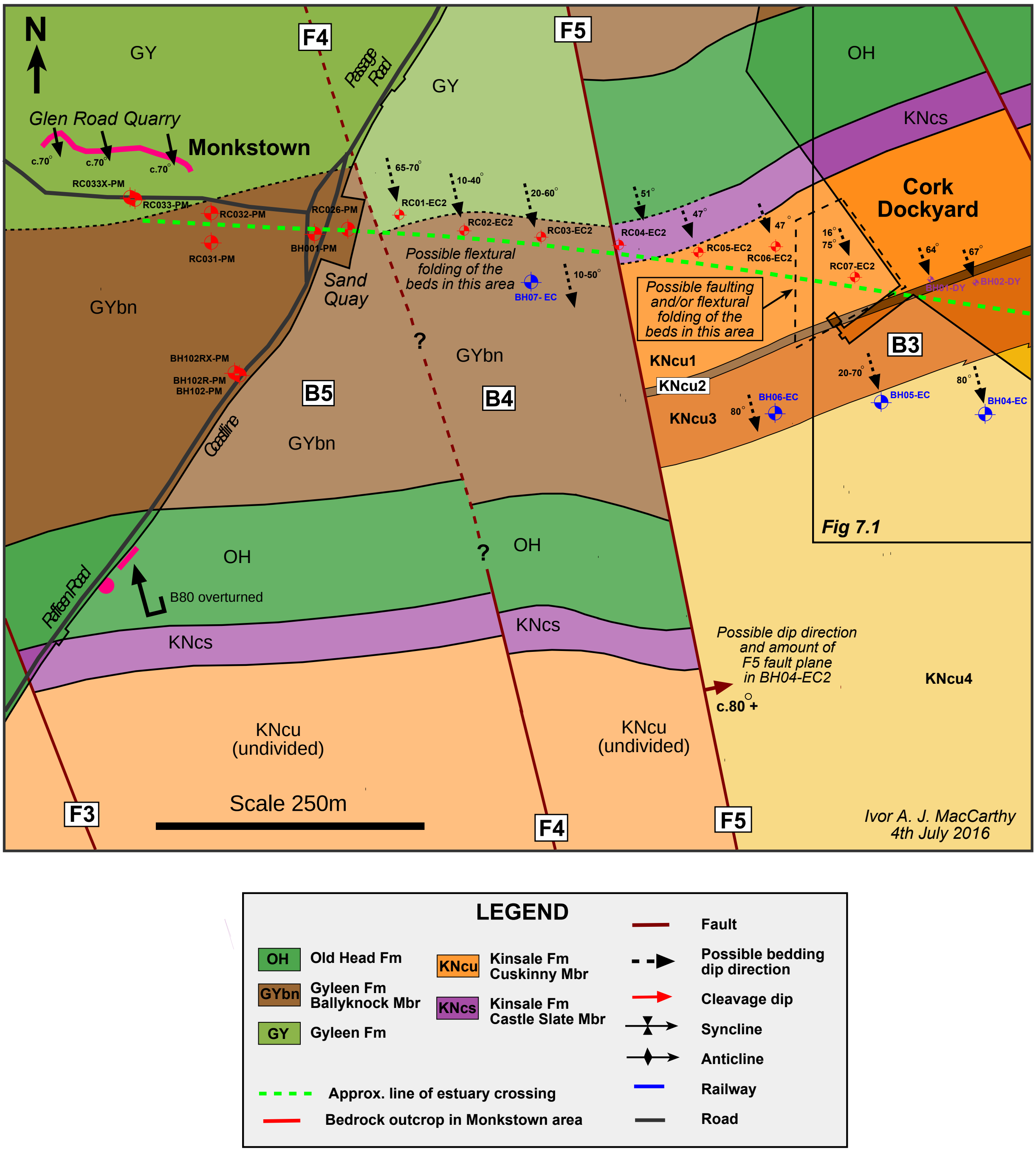

Figure 19 - Dr MacCarthy predicted bedrock map (Figure 13.1a - July 2016)

APPENDIX C

CONSTRUCTION METHODOLOGIES

Dredging

The traditional method of installing crossings of this type is by open cut techniques i.e. to dredge a trench through the foreshore and channel bed and lay the pipelines within.

This method, in pure construction terms, is normally more cost effective than trenchless methods; however, it suffers from significant impacts and risks, including:

a. Significant environmental damage through the foreshore sections
b. Increased risk of anchor damage to the in-service pipeline
c. Greater conflict with existing utilities and other 3rd party facilities
d. Ground movement risk, especially in the urban environment
e. Increased personal (public and operatives) safety risk over trenchless methods

These impacts and risks are often difficult to quantify and licencing authorities, including those that have authority over the marine environment, will frequently block attempts for such works unless it can be shown other methods are considerably less desirable.

Trenchless installation methods are preferred over dredging for this crossing as the impacts on the marine ecology would be significantly less.

Tunnelling

Due to the necessity to construct deep shafts at each end of a tunnel and that the final pipe system would need to be installed inside a primary lined larger diameter envelope, a tunnelled approach to the crossing is unlikely to be cost effective in comparison to a directionally drilled installation. The construction and financial risks associated with tunnelling are at least equal to those of drilling through the geology envisaged.

Tunnelling is best undertaken in homogeneous conditions, which means that maintaining the alignment within the bedrock OR within the superficial deposits alone minimises risk. For the proposed crossing the depth of reliable superficial deposits is limited and passage at a constant grade below the deepest section of the main river channel limits options for a “soft ground” crossing. Furthermore, there is the risk of encountering cobbles and boulders in the materials above the bedrock. This increases risk, especially as the tunnel diameter decreases.

Tunnelling with a Tunnel Boring Machine (TBM) within the bedrock carries similar risks to those of directional drilling. Fragmented and poor quality rock as well as the uncertainty surrounding fault zones means that tunnelling at significant depth below the Passage carries inherent risk.

Tunnelling within the bedrock would require shafts of perhaps 40m depth. These would be significant cost elements for the project.

The main driver for the primary tunnel diameter would be the safety aspects of undertaking a bore of around 1km in length. A diameter of at least 2m would likely be required. A tunnel diameter would permit twin HDPE pipes to be installed in a single tunnel. The volume of soil excavated for a larger tunnel, and hence soil waste disposal off site, is greater than for the directional drilling process discussed below.

HORIZONTAL DIRECTION DRILLING (HDD)

HDD is ideally suited to installing long distance pressure pipelines and thus if technically feasible the logical solution for pipeline crossings.

Figure 20 - Horizontal Directional Drilling Rig (Thailand)

Horizontal Directional Drilling (HDD) is a Trenchless Technology process whereby a pipeline is installed from one point to another without excavating a trench.

The process commences by using a Drilling Rig to drill or bore a small diameter Pilot Hole from the Launch Site to the Reception Site. The alignment or Bore Profile of this Pilot Hole in both the horizontal and vertical is planned beforehand and consists of an initial slanting section followed by a vertical curve to take the drill to the required depth. It then typically continues horizontally until towards the exit end when the drill is typically steered back up towards the surface and the Reception Site.

Drill entry angles are typically circa 10 degrees although up to 18 degrees can normally be accommodated without special considerations. Entry angles greater than the drilling rig is designed for add complexity and safety issues for the drilling crew and should be avoided. The maximum angle capacity for the rig depends on the manufacturer.

Exit angles are normally shallower, typically less than 10 degrees, to provide the best alignment for pipe pullback.

Horizontal curves can be incorporated in addition to vertical curve(s) though it is normal practice to steer only in either the horizontal or vertical plane at any given time and not in both planes simultaneously. “S” shaped reverse curves are normally avoided where possible as these configurations place additional loads on the product pipeline during pullback into the prepared hole.

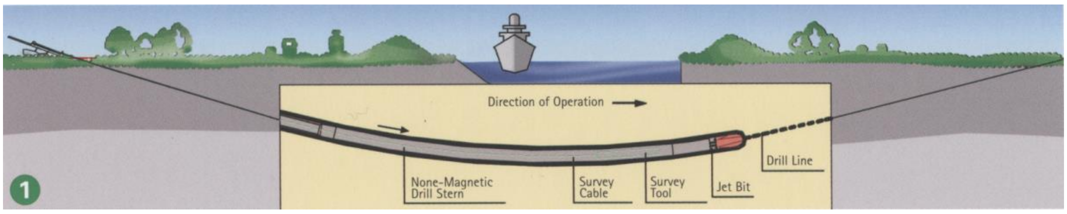

Figure 21 - HDD Stage 1 - Pilot Bore (Image courtesy of Herrenknecht)

Down Hole equipment at the front of the drill called the Bottom Hole Assembly (BHA) enables the Pilot Hole to be advanced and at the same time steered to the required or planned Bore Profile.

Horizontal positional accuracy requires careful control, especially for closely spaced bores. Common practice where a high degree of accuracy is required is to use a surface coil/grid to induce a local magnetic field within which the downhole steering tool can be correctly orientated. When combined with a system employing inertial guidance the position of each bore can be accurately tracked. For highest accuracy the latest technology employs an optical gyroscope system which can provide sub-metre monitoring accuracy when required.

Should a borehole become off position the downhole assembly is typically withdrawn some distance and then sent off on a revised course. In rock formation the unused section of hole may be grouted to enable the drilling bit to leave the old hole alignment. In the unlikely event that a partially completed bore has to be abandoned and re-drilled the limited available separation space between proposed pipes may require changes to the developed design for the permanent connection works.

When drilling through rock the pilot hole is normally created using a bit driven by a downhole motor. This motor is powered by the drilling mud pumped through it. Due to the arrangement of the mud motor and other components of the BHA the minimum steerable radius for the pilot bore is limited. It is the minimum bend/turning radius of the drill pipe and BHA and not the proposed HDPE that is likely to limit the minimum radius of the bore profile.

Mud motors require significant flow rate and therefore a significant volume of suitably formulated drilling mud, and hence a good supply of potable water. In turn the process of mud recycling is a larger operation. Operation of a mud motor also requires a higher mud pump pressure than for other stages. While the majority of the pressure dissipates in driving the motor the remaining pressure combined with the high fluid flow volume can increase the risk of inadvertent fluid returns, especially at shallower elevations or in more permeable formations.

Figure 22 - Mud Motor (Slimdril)

The Drilling Mud is typically a mixture of naturally occurring or Polymer modified Bentonite Clay and water, however bentonite clay can be toxic to fish and other marine inhabitants at higher concentrations and where there are ecological concerns the conventional products are normally changed to those containing no toxic polymer formulated substances, though typically these materials perform less well than bentonite based products. The drilling mud is pumped down to the BHA from the surface through hollow Drill Pipe. Individual sections of Drill Pipe (also referred to as Joints) are added at the Drilling Rig and pushed forward to advance the BHA from the Launch Site to Reception Site. Ground cut by the drilling bit is carried back in the circulating Drilling Mud along the outside of the Drill Pipe to the Rig Side where it is deposited in a shallow pit at the drill Launch Site. Spoil laden Mud emerging from the bore is called the Returns. The Returns are typically pumped to a Mud Recycling System that removes the cut solids enabling the cleaned Mud to be reused for drilling. Recycling reduces waste and limits the discharge of materials to the environment.

On completion of the Pilot Bore the bored hole contains all the Drill Pipe inserted, or Drill String, surrounded by Drilling Mud.

The Pilot Hole is relatively small and typically needs to be enlarged in one or more enlarging or pre-reaming phases until large enough in diameter to accommodate the Product Pipe.

On the majority of projects reaming is undertaken by drawing and rotating a new BHA consisting of reaming tools/hole openers inserted into the drill string at the Reception Site. This is called Back Reaming.

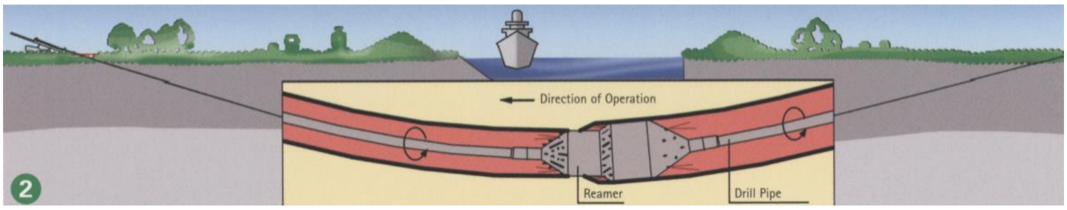

Figure 23 - HDD Stage 2 - Reaming (Image courtesy of Herrenknecht)

During the Reaming phases Drilling Mud continues to be pumped from the Drilling Rig down the Drill String to the reaming/hole opening BHA where it exits through Jets in the tools. As with the Pilot Bore the ground that is cut during reaming becomes mixed with the Drilling Mud and is transferred to the surface through the circulation of the Drilling Mud in the open bore. Typically, returns from back reaming operations will occur to the reception site of the crossing. This solids laden mud must be cleaned and returned to the rig side to be reused. Contractors may wish to drill and utilise a second pilot hole as a mud return line, in which case the mud can be returned to the rig side for processing. Alternatively the mud is pumped into tankers for the journey back to the mud separation plant on the rig side. In some instances the contractor will process the mud at the reception site using a separate separation and processing plant, though the cleaned mud will still need to be transferred via a mud line or tankers to the rig side storage for reuse.

At every step of the process the cut bore is maintained open by the presence of the Drilling Mud. The Mud is specially formulated and mixed to provide properties that both maintain the Mud within the cut bore and also support the bore against collapse, especially important in weak, fractured and unstable formations. At the periphery of the bore smaller lighter particles are easier to hold in place than larger heavier particles and this means that drilling through fine grained strata is typically less challenging than drilling through coarser grained materials or where loose rock is present. The presence of fractured or closely bedded rocks or where there are other discontinuities, especially combined with high angle of dip, can make drilling difficult because of instability of the rock mass at the periphery of the bore. Over excavation can be anticipated, as can be the need to undertake additional proving runs before the product pipe is installed.

Because the Drilling Mud is pumped down the Drill String under pressure there is always pressure within the bore during Pilot Hole Drilling or Reaming. If the passageway for circulating Mud is impeded or if an easier path for the Mud to escape presents itself drilling Mud can escape from the bore and will often migrate to the surface to become Inadvertent Returns (i.e. Returns emitting from somewhere other than the end of the bore). Inadvertent returns are generally unwelcome in directional drilling operations for several reasons, including the environmental problems they present in the vicinity of the escape (which may be some distance from the pipeline) or because the ability to keep the ground laden Drilling Mud flowing properly to one end of the bore or the other (or both) is compromised. Inadvertent returns are typically sealed with special Lost Circulation Materials introduced directly into the drill string or other special chemical grouts if the ground conditions and depth is sufficient. The risk of inadvertent returns can be reduced by drilling through the most competent horizon and avoiding areas of loose of soft strata.

Reaming, or hole opening in rock formations, increases the diameter of the cut bore in increments. For example, 12-inch (300mm) to 18-inch (450mm) to 26-inch (610mm) to 30-inch (750mm) to 36-inch (900mm). The final diameter reamed is typically between 1.2 to 1.5 times the external diameter of the Product Pipe with the diameter required increasing as bore complexity increases and bore quality decreases.

Figure 24 - Hole Opener

The additional diameter provided by the additional pre-reaming operations enables the Drilling Mud, and remaining cuttings it contains within the bore, to be displaced and passage around the Product Pipe as it is pulled into the bore.

Reaming tools vary depending upon the type and/or hardness of the ground needing to be cut or whether they are being used in a primary cutting or proving (verifying and/or conditioning) role. On this project Hole Openers would typically be deployed for pre-reaming in the rock strata anticipated.

Once the bore has been reamed to the required diameter and one or more proving passes made to confirm it is ready to receive the Product Pipe the pipe is typically connected to the drill pipe at the reception site and pulled back through the bore using the Drilling Rig. The staging of the pipe in line with the bore is critical to ensure frictional loads at the pipe launch site are minimized. The pipe is then pulled back into the bore using the Drilling Rig in a continuous operation. Jointing of pipe sections into a single string is advisable as any jointing of the pipeline necessarily introduces a time delay into the pullback operation and this can increase pullback loads significantly as the drilling mud around the installed section of pipe increases in shear strength while standing.

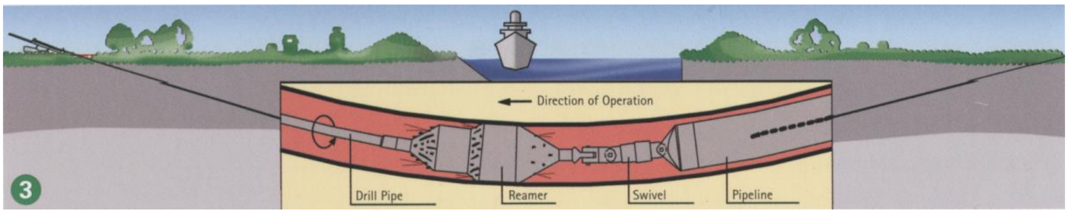

Figure 25 - HDD Stage 3 - Pipe Pullback (Image courtesy of Herrenknecht)

Direct Pipe

Figure 26 Herrenknecht Direct Pipe® system

Herrenknecht's Direct Pipe® system is designed to offer a microtunnelling type installation for pressure or other non-gravity (linear slope) pipelines.

Similar to HDD the pipe is launched, though without a pilot phase, directly into the ground from the surface.

A slurry based microtunnelling machine is used at the leading end of a continuous welded steel pipeline. A pipe thruster unit grips the steel pipeline externally in order to advance the microtunnelling machine and the pipeline into and through the ground.

The use of a Direct Pipe approach on a crossing length of over 1km would require the direct installation of a steel pipe of at least 1.2m or possibly 1.5m diameter. This would create a casing of sufficient size in which to install the twin sewer mains into a single crossing. The installation of a single smaller diameter steel casing to house a single DN500 sewer main is not possible due to length of the crossing required.

The methodology requires considerable space behind the launcher, ideally at least 500m. The limited space behind the proposed pipe entry/exit at Cork Dockyard and the rising ground elevation and limited width of Glen Road, Monkstown make the feasibility of the method doubtful at best.

Furthermore, the sandstone rock formations through which the tunnelling will pass have high quartz content which will create aggressive wear of the cutter tools at the front of the tunnelling system. Typically with this Direct Pipe method the whole pipeline would be withdrawn to enable tools to be changed before the machine and pipe being reinserted into the bored hole. This process would be extremely challenging in the conditions at this site

Due to the space restrictions and the ground conditions the Direct Pipe method is not considered feasible for this crossing option.

APPENDIX D

CV – Mr A J Robinson

Andrew J. Robinson **Résumé**

Principal

B.Sc. Civil Engineering, Aston University, 1984

Member, British Tunnelling Society

Member of the UK Society for Trenchless Technology

Andy Robinson has over 30 years' experience in the underground utility installation sector. His primary experience is in the field of tunnelling, underground space and trenchless (No-Dig) technologies including tunnelling, microtunnelling & pipe jacking, Horizontal Directional Drilling, shaft works and jacked underground structures.

Andy has specialized in underground design, construction management and expert analysis and prior to entering the engineering services field was employed as a project manager for a major UK tunnelling contractor and operations manager of a tunnelling plant manufacturer.

Andy has been involved with more than 270 trenchless projects. His expertise covers all aspects of project development from project evaluation and feasibility study through conceptual and detailed engineering design to equipment and materials selection, project construction and operations management. He is also experienced in forensic analysis of tunnel and drilling system data and providing specialist advice during dispute resolution. He has a strong practical understanding of geotechnical and geological conditions and their impact on the underground works and how they are constructed.

He has extensive experience in shaft construction undertaken by the caisson method and has supported contractors in the US and the Middle East in this field of work as well as having being heavily involved in this method of shaft construction during his time working for a tunnelling contractor during the 1980's.

His international experience is extensive having worked in Europe, SE and Far East Asia, North, South and Latin America, The Caribbean, the Middle East and Australasia. He has managed projects for water, sewer & electric utilities, municipalities and highway departments, private developers and contractors and a summary of his relevant experience is attached.

He has been at the forefront of developments and innovations in the trenchless technology, microtunnelling and tunnelling field and has been a team member on two projects that have previously been recipients of the Trenchless Technology "Project of the Year" award. He has presented a number of papers to international seminars and has conducted training and teaching seminars and workshops for Engineers and construction managers on projects around the globe.

Andy brings to projects his experience and expertise in technical and economic evaluation and design. This includes risk evaluation and mitigation, and assessment, quantification and constructability evaluation and review of projects. As a detailed designer, he is equipped with a strong appreciation of the subsurface environment and the natural ability to adapt, while maintaining the high discipline standards required in achieving effective quality control and management and a workable, constructible design. During construction and dispute resolution Andy utilises his extensive practical experience from the construction and construction management field.

Project Experience (Selective – HDD Focus)

Coolberrin Wind Farm - Coolberrin to Lisdrum 38 kV cable circuit; *Project Consultant* for the high level review of potential trenchless crossings of rivers and major highways for a multi-duct installation. Evaluation and consideration of drilling and tunneling methods.

Monard Sewerage Scheme, Glashaboy Estuary Crossing; *Project Consultant;* reviewing the technical feasibility and environmental considerations for a trenchless crossing of the Glashaboy River through mixed sedimentary geology required for a new sewer pipeline to service the Monard Strategic Development Zone.

Western Link High Voltage Direct Current project, UK: Technical *Expert* evaluating Directional Drilling difficulties and delays in the prevailing geological conditions at the cable landing sites in England and Scotland.

Galway West 110 kV UGC - HDD at Corrib River, Co. Galway, Ireland: *Project Consultant* evaluating the technical feasibility of crossing the river by Horizontal Directional Drilling through karstitic limestone and preparation of technical specifications. The project requires the installation of a multi duct bundle over a length of 300m with the alignment passing adjacent to the ruins of historic Menlough Castle.

Cork Lower Harbour Main Drainage Scheme, Cork Ireland: *Project Consultant* responsible for the Estuary Pipeline Crossing Feasibility Study. The project requires two 500mm diameter, 1km long pressure sewer pipelines to be installed below the River Lee / West Passage between Ringacoltig and Monkstown through laminated mudrock, siltstone and sandstone bedrock.

Rio Namur Outfall, Kwajalein Atoll, Marshall Islands *Expert Witness***,** for the arbitration in the USA relating to a dispute regarding an HDD installation for a new sewer outfall through coral rock formation.

Kilpaddoge-Moneypoint HV Cable Installation. Moneypoint Cable Landings. *Project Consultant*, for the feasibility of trenched or trenchless installation of eight cable conduits required to land submarine high voltage cables at en exposed shoreline location through variable sedimentary rock geology and complicated existing site constraints and shore protection structures.

The Fourth Transmission Pipeline Project, Thailand; *Technical expert and later court expert witness*, for the review of conditions and operations undertaken by drilling contractor in installing 1.5km of 1067mm diameter gas pipeline through alluvial/sandstone ground conditions. Drill string failure evaluation and data review.

North East Offshore and Tobago Pipeline. Trinidad. *Arbitration Support***.** Technical Expert advising the Employers UK legal team on HDD matters during the preparation for format Arbitration. The work related to the failure to complete the installation of a 36-inch offshore to onshore steel pipe installation.

Harbour Area Treatment Scheme Stage 2A Ap Lei Chau to Aberdeen, Hong Kong; Technical Expert, for the review of HDD operations through reclaimed land fill and hard rock during installation of twin 1.3km long 600mm diameter sewerage pumping mains.

Burrows to Hazeldown Pipeline, Devon; Technical Expert Witness during the Adjudication process following technical and contract issues resulting from HDD operations to install 600m of 300mm diameter 25 bar pipeline through variable geology.

Belmullet Wave Energy Test Site - Co. Mayo, Ireland: Project consultant (HDD), for the installation of offshore to onshore pipes and cable conduits for the Sustainable Energy Authority of Ireland (SEAI) near and far shore offshore wave energy test site off the coast of northwest Ireland. Work undertaken involved the analysis of the subsurface conditions in the near-shore area at proposed cable and pipeline landing sites and the assessment of the technical feasibility and economics of installing the required pipes and conduits by HDD methods within the challenging local environment, including marine and foreshore protected and regulated regions.

Sizewell, Suffolk – Greater Gabbard Offshore Windfarm, UK: *Project Engineer and advisor, HDD,* for the design and build installation of the three land to sea cable conduits bringing the three 132kV offshore marine cables to shore for this major new windfarm. Work included the preparation of a specification for three number 400mm diameter, each 322m long, Horizontal Directional Drilled conduits, technical support to the project team, review and interview of HDD contractors during tender stage and review of HDD contractor's proposals.

Carrington Power Station, Carrington, Cheshire, UK: *Project advisor* for the preliminary feasibility assessment of an alternative 750m long 600mm diameter gas main installation by Horizontal Directional Drilling (HDD) for a 800MW CCGT Power Plant under construction.

Galway – Salthill 110kV River Corrib cable crossings, Galway, Ireland: *Project Engineer* evaluating the technical feasibility of crossing the river by Horizontal Directional Drilling or Tunnelling and provide recommendations for further geotechnical investigations to confirm the viability of the options for the subsurface conditions present at the site. Work including method statements and risk analysis required by Galway City to safeguard Natural Heritage Area (NHA) and Special Area of Conservation (SAC) sites above the proposed alignments.

Holyhead Long Sea Outfall, Wales, UK – *Technical Advisor* to the owner/contractor alliance team for horizontal directional drilling of a 900m long 500mm diameter HDPE long sea sewer outfall installed by HDD through hard rock strata.

Balleally, Ireland - HVDC East West Interconnector, Balleally Landfill Site, Ireland: *Project Advisor* considering the contamination aspects of soil and groundwater due to Horizontal Directional Drilling operations adjacent to an existing landfill site.

Bellevue Pump Station Upgrade, Bellevue, Seattle, WA, USA - *Project engineer* evaluating tunnelling and horizontal directional drilling feasibility for a 2,100m long pumping main upgrade through alluvial and organic soils.

Finglas – Shellybanks 220kV Feeder Cable – Electricity Supply Board, Dublin, Ireland - *Technical Advisor* for the evaluation and design of a 425 m crossing of the River Liffey within Dublin Port. The crossing required the installation of a 220kV feeder cable and associated pilot cores. Evaluation for either a deep tunnel or horizontal directional drilling was carried out with the crossing ultimately completed by horizontal directional drilling through water bearing sands and gravels and silty clay at depth. The final design called for 5 No. 250mm horizontally close spaced polyethylene ducts.

Ayalon Collector Tel Aviv Israel; *Tunnelling consultant* for the design of 6,000 m of 1.6 m diameter sewer by microtunnelling plus a HDD crossing in soft soil conditions below the water table and with limited access.

APPENDIX E

Cork Lower Harbour Main Drainage Scheme, Geology of the Cork Dockyard-Monkstown Estuary Crossing

Ivor MacCarthy, July 2016

Dr. Ivor A. J. MacCarthy
Consultant Geologist

34, Endsleigh,
Douglas Road,
Cork.

Phone: 021-4293496, 087-6508017
e-mail: i.maccarthy@ucc.ie

Mr. Shane Cosgrove,
Associate,
Nicholas O'Dwyer Ltd.,
Unit E4,
Nutgrove Office Park,
Nutgrove Avenue,
Dublin 14.

8th July 2016

CORK LOWER HARBOUR MAIN DRAINAGE SCHEME

Geology of the Cork Dockyard-Monkstown Estuary Crossing

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PART C-CORK DOCKYARD ONSHORE AREA (p.71)

BH01-EC2 to BH07-EC2. The colours shown represent the general colours of the bedrock. The scale shown is in metres.

15-CORE RECOVERY AND ROCK QUALITY

Fig 15.1. Summary logs showing (a) TCR and RQD for RC01-EC2 to RC07-EC2 and (b) Rockhead profile along estuary crossing (based on *Priority* core logs dated June 2016).

Fig 15.2. Cross-section of the estuary crossing showing the rock quality (RQD) distribution pattern (based on *Priority* core logs dated June 2016).

16-CORE IN ONSHORE TO OFFSHORE ESTUARY EC BOREHOLES

Fig 16.1. Summary offshore EC borehole logs.

Fig 16.2. Summary Monkstown onshore PM to offshore EC borehole logs combined.

17-ROCKHEAD DEPTH AND THICKNESS OF SUPERFICIAL DEPOSITS

Fig 17.1. Seabed map of the Cobh to Monkstown crossing area.

Fig 17.2. Overburden thickness in the Cobh to Monkstown crossing area.

Fig 17.3. A-Depth to bedrock in the Cobh to Monkstown estuary crossing area (Apex Geoservices 26th June 2013). Note: The depth to bedrock shown here is less than indicated by the borehole information (see Fig 11.1). B-CHIRP seismic profile along the line X-Y in Fig 16.3A-The strong multiple may reflect horizons in the lower parts of the superficial deposits and/or parts of the rockhead zone.

Fig 17.4. Distribution pattern of superficial deposits in the offshore area adjacent to the estuary crossing in Boreholes BH01-EC2 to BH06-EC2.

Fig 11.1. (Duplicate). Interpreted contours of the rockhead in the Cork Dockyard area.

APPENDICES (p.133)

APPENDIX C-Nomenclature and Classification Schemes

EXECUTIVE SUMMARY

This report describes, interprets and characterises the bedrock and superficial geology of the estuary crossing area from Cork Dockyard, Cobh to Monkstown, County Cork.

Onshore bedrock outcrops on either side of the estuary were geologically mapped. This, together with information from boreholes and published maps, was used to construct a detailed geological map and cross-sections depicting the theoretical three-dimensional distribution of various rock formations.

The bedrock consists of Late Devonian and Early Carboniferous sedimentary rocks (sandstones and mudstones) that have undergone low-grade metamorphism and extensive structural deformation and fracturing.

There are up to three important NNW-SSE orientated sub-vertical faults intersecting the estuary crossing. The precise character of these faults is not known. The bedrock also contains a number of other faults of varying scales and orientation.

The bedrock contains extensive large-scale flexuring and folding of bedding planes across the area. Small-scale parasitic folds are also present. Fold axes trend ENE-WSW.

The principal discontinuities in the crossing area are bedding, cleavage, joint and fault planes. Apart from fault planes, these are closely spaced throughout and are arranged in various orientations.

The bedrock in the offshore estuary crossing area is likely to be similar in character to (a) the bedrock that outcrops on either side of the estuary and (b) bedrock seen in onshore and offshore boreholes.

The downhole quality of the bedrock is variable and improves with depth in many of the boreholes.

The rockhead descends to at least -36.7mOD in the central part of the channel. It could be lower in localised parts of the channel but this is uncertain.

Superficial deposits resting on the bedrock descend to at least -36.7mOD and are dominated by clayey and sandy gravels, silts and clays. Gravels are likely to be porous and highly permeable.

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DETAILED SUMMARY

This report describes, assesses and characterises the bedrock and superficial geology of the area of the estuary crossing from Cork Dockyard, Cobh to Monkstown, County Cork.

1-Onshore bedrock outcrops on either side of the estuary were geologically mapped. This, together with information from boreholes and published geological maps, was used to construct a detailed geological map and cross-sections depicting the theoretical three-dimensional distribution of various rock formations.

2-Core from onshore (RC01-DY to RC08-DY) and offshore boreholes (RC04-EC, RC06-EC, RC07-EC, RC08-EC and RC01-EC2 to RC07-EC2) was examined and logged for this report.

Selected samples were collected from the above core for age dating by palynological techniques. This was carried out in order to aid in identifying stratigraphical levels and the location and effects of any faulting in the area. The samples were sent to the Geology Department, University College Cork for analysis. The results were used in the construction of the geological bedrock maps (Figs 6.2, 7.1, 7.2, 13.1a & 13.1b).

3-Information from the following onshore and offshore borehole records (RC31-PM, RC32-PM, RC33XPM, BH001-PM, RC026-PM, RC05-EC, RC09-EC, BH16-CH, BH16A-CH, BH17-CH and RC102-CH) was examined, summarised and utilised in this report.

4-The absence of information on the direction of dip of bedding planes in the dockyard and offshore areas has a significant impact on the ability to assess the structural pattern in the bedrock geological map for those areas.

5-The bedrock in the estuary crossing area consists of Late Devonian and Early Carboniferous sedimentary rocks that have undergone low-grade metamorphism and extensive structural (folding, faulting and cleavage development) deformation.

6-The bedrock consists of siliciclastic sedimentary rock and is divided into five stratigraphical rock units (the Old Head Formation, the Gyleen Formation, the Gyleen Formation Ballyknock Member, the Kinsale Formation Castle Slate Member and the Kinsale Formation Cuskinny Member).

The Gyleen Formation is distinguished by regularly alternating purple mudstones and fine to medium grained siltstones and grey green sandstones. The Ballyknock Member consists of rapidly alternating green and grey, fine to medium-grained siltstones and sandstones. The Old Head Formation contains well-bedded heterolithic rocks and the Castle Slate Member is composed of grey mudstones. The Cuskinny Member is composed sandstones (c.67%) and mudstones (claystones/siltstones) (c.33%). This bulk lithological composition of these units is consistent across the region.

7- Petrographical analyses of selected levels in Boreholes BH04-EC to BH09-EC. showed that the mineral Quartz is an important component of the bedrock, accounting for c.57-84% in sandstones and c.20% in mudstones in these boreholes. It would be important to carry out similar analyses on the bedrock in the DY and EC2 boreholes.

8-Two large-scale onshore ENE-WSW (c.070°) striking folds are identified in the Cork Dockyard area. A number of small-scale parasitic folds are also present. The large-scale folds may take on a monoclonal form. Similar folds are expected in the remainder of the estuary crossing.

9-Two important NNW-SSE orientated sub-vertical faults (F5 and F8) intersect the crossing. A possible third NNW-SSE fault (F4) may also be present. The precise character of these faults and the extent to which other faults may be present are not known.

10-The principal discontinuities in the area are bedding, cleavage, joint and fault planes. Apart from faults, these are ubiquitous in the bedrock and are closely spaced in the area of the estuary crossing. They are arranged in various orientations that have been plotted in this report. Joints tend to be more common or more prominent in sandstones than in the finer-grained lithologies.

11-Two sets of onshore outcropping discontinuities (joints) are recognised in the Cork Dockyard area. These are (1) a NE-SW set and (2) a NW-SE set. These sets are likely to be also present in the estuary crossing. The angle of intersection of Set 1 with the proposed crossing ranges from 20-35° (mean c.27.5°). The intersection of Set 2 with the crossing ranges from 17°-83° (mean c.50°).

Strike orientations of steeply inclined joints in the Monkstown onshore area range from NW-SE through to NNE-WSW.

Cleavage and bedding orientations trend ENE-WSW.

The orientations of joint and cleavage planes (discontinuities) exposed in the onshore areas on either side of the estuary are broadly similar. This pattern should be anticipated in the area of the offshore estuary crossing.

12-A substantial proportion (c.30%) of the core from the DY boreholes contains weathered and non-intact broken levels (NI) along with gaps.

About 22% of EC2 core contains weathered and non-intact broken levels (NI) along with gaps.

13-The downhole quality of the bedrock is variable and improves with depth in many of the boreholes.

14-The strength of the un-weathered rock in the core examined ranges from *Moderately Strong to Very Strong*.

15-Core recovery values for the onshore DY core in the drill zone of interest show a consistently high Total Core Recovery (TCR) of 95%. Average Solid Core Recovery (SCR) values are 45% while average Rock Quality Designation (RQD) values are 21%.

16-Core recovery values for the offshore EC2 core in the drill zone of interest show consistently high Total Core Recovery (TCR) of 96%. Average SCR values are 61% while average RQD values are 32%.

There are several potential geological causes for these patterns including variations in lithology, presence of heterolithic levels, bed/lamina thicknesses, weathering patterns, faulting, jointing, cleavage planes and fracturing associated with localised folding.

17-The bedrock in the offshore estuary in Block B3 is likely to be similar to that in the onshore area on the eastern side of the crossing (i.e. Blocks B1-B3).

18-The bedrock in the offshore estuary in Blocks B4 and B5 is likely to be similar to that outcropping in the onshore Monkstown area.

19-The unexpected occurrence of small-scale mineralised bodies and/or intrusions in the offshore estuary area, possibly associated with faulted zones, cannot be ruled out in the absence of a detailed geophysical survey and site investigation.

20-The rockhead descends to at least -36.7mOD in the central part of the channel. It is possible that it may be lower in localised parts of the channel.

21-Superficial deposits resting on the bedrock are dominated by clayey and sandy gravels, silts and clays. These thicken from the onshore areas towards the estuary. The gravels are likely to be porous and highly permeable.

PART A-INTRODUCTION

1-INTRODUCTION

The report was commissioned by *Nicholas O'Dwyer Ltd., Consulting Engineers* on behalf of *Irish Water*. The report is concerned with describing, assessing and characterising the geological conditions in the area of the estuary crossing from Cork Dockyard, Cobh to Monkstown, County Cork (Figs 1.1, 1.2 & 1.3).

This assessment is to inform the *Estuary Crossing Feasibility Report* and forms part of the *Cork Lower Harbour Main Drainage Project 146B* request for an alteration to the terms of the development *Cork Lower Harbour Sewerage Scheme* ABP Register Reference YA0005.

2-SITE INVESTIGATIONS AND DATA SOURCES

2.1-Site Investigations

Four sets of boreholes were drilled (see locations in Figs 6.2, 7.1 & 13.1).
These include the following;
EC1 boreholes-Offshore (*Causeway Geotech*)
EC2 boreholes-Offshore (*PGL Priority Geotechnical*)
DY boreholes-Cork Dockyard onshore (*PGL Priority Geotechnical*)
CH boreholes-Cork Dockyard onshore (*PGL Priority Geotechnical*)
PM boreholes-Monkstown onshore (*PGL Priority Geotechnical*)

2.2-Data Sources

Data from the following sources are used in this report;

1-*Nicholas O'Dwyer Ltd.* - Drawing No. 20506-SI-EC-02 - Borehole profile of onshore estuary crossing

2- *PGL Priority Geotechnical* report P13097 dated 12th November 2015.
Borehole logs BH01-DY to BH08-DY.

3-*PGL Priority Geotechnical* report P13097 dated 22nd January 2015.
Borehole logs BH16-CH, BH17-CH, BH102-CH and BH103-CH

4-*Priority Geotechnical* report dated November 2015.
Borehole logs RC01-DY to RC08-DY.

5- *Priority Geotechnical* logs of RC01-EC2 to RC07-EC2 dated June 2016.

6-*Causeway Geotech* June 2015
Cork Lower Harbour Main Drainage Scheme-Ground Investigation Factual Report. Report 13-381 (BH01-EC to BH09-EC).

7-*Causeway Geotech* June 2015
Cork Lower Harbour Main Drainage Scheme-Ground Investigation Interpretive Report. Report 13-381a (BH01-EC to BH09-EC).

8-*Boregis* 8th July 2016
Cork Lower Harbour Main Drainage Scheme-Estuary Pipeline Crossing Feasibility Study.

9-*Apex Geoservices* 26th June 2013
Report on the Geophysical Investigation for the KYR12-05 Cork Harbour and Approaches.

10-*Infomar* Programme INFO 13 COR Bathymetry. *Geological Survey of Ireland and Marine Institute.*

11-*AQUAFACT International Services Ltd*. November 2013
Field Report Side Scan Sonar and Marine Magnetometer Survey at Passage West and Side Scan Sonar Survey of Ringaskiddy Outfall, Cork Harbour.

12-Field surveys of onshore bedrock outcrops by the author.

13-Core examination carried out from selected EC boreholes, DY boreholes and EC2 boreholes by the author.

2.3-Geological maps in this report
The geological maps in this report are based on; (1)Borehole records and examination of selected rock core from site investigations (PM, CH, DY, EC and EC2), (2)Examination of adjacent onshore bedrock outcrops and (3)Published bedrock geological maps (MacCarthy et al. 1978, MacCarthy 1988, Sleeman & Pracht 1995 & Meere *et al*. 2013).

The bedrock in this region is known to be structurally complex. Consequently, representations of stratigraphical boundaries and structural features between control points (i.e. boreholes and outcrops) on the maps are speculative. Representations of these elements on the maps are the simplest interpretations.

3-METHODS
This report describes the regional topographical and regional geological setting of the estuary crossing area initially. This approach is adopted as an understanding of the subsurface bedrock in the estuary crossing relies on knowledge of the geology of peripheral adjacent areas as well as the site investigation reports. Such areas contain outcropping bedrock of the same or similar structural and lithological character to that which might be encountered in the crossing.

The following procedures were carried out;

1-An examination of the geotechnical reports listed above was carried out to identify lithologies and structural features. Selected information from these reports was summarised and utilised in this report. These summaries are shown in small font and *italics*.

2-Geological logging of the rotary core from Cork Dockyard (RC01-DY to RC08-DY) and the offshore area (RC01-EC2 to RC07-EC2) was carried out. Selected parts of RC04-EC, RC06-EC, RC07-EC & RC08-EC were examined. The logging recorded the lithological and sedimentological content, weathering information, core recovery and structural/discontinuity information of the bedrock (Figs 7.3, 7.4, 14.1-14.3, 15.1 & 15.2).

3-The logged data was used to generate histograms showing the lithological content of core boxes in each borehole (Figs 7.3-7.14, 14.4-14.10).

4-The logged data was used to plot the rock quality for DY core (Fig 10.1).

5-The logged data was also used to illustrate the lithological correlation/distribution pattern across the eight boreholes at Cork Dockyard (Figs 7.15 & 14.11).

6-Summary schematic bedrock lithological correlations based on onshore and offshore borehole records were produced (Figs 13.22, 16.1 & 16.2).

7-Strike orientations of discontinuities from onshore bedrock outcrops were plotted (Figs 7.17 & 13.20).

8-Stereographical projections of poles of representative bedding, joint and cleavage planes in the onshore bedrock outcrops were plotted (Figs 7.18 & 13.21).

9-Discontinuity characteristics at onshore outcrops were recorded (Appendix A9).

10-Selected samples were collected from the core for age dating by Palynological techniques. This was carried out in order to aid in identifying stratigraphical levels and the location and effects of any faulting in the area. The samples were sent to the Geology Department, University College Cork for analysis (Appendix A2).

11-Geological mapping and logging of onshore bedrock outcrops along the Rushbrooke Railway cutting, the coastal section at Ringacoltig, Glen Road and Passage Road, Monkstown was carried out.

12-Photographs of onshore bedrock outcrops were annotated with geological information (Figs 13.2-13.19, Appendices A6 & A7).

13-Detailed geological maps were drawn for the area (Figs 6.2, 7.1, 13.1a & 13.1b).

14-Geological cross-sections of the area were constructed (Fig 7.2).

15-Detailed statigraphical logs were drawn for selected bedrock exposures (Figs 13.23 &13.24) and EC2 boreholes (Fig 14.11).

16-A contour map of the rockhead in the estuary crossing area was drawn (Fig 11.1).

17-Borehole data on the superficial deposits were summarized in a series of logs (Fig 12.1).

18-The lateral distribution pattern of the various types of superficial deposits was plotted in correlation charts (Figs 7.16, 12.1, 12.2 & 17.4).

4-LAYOUT OF REPORT

The text of this report consists of eight parts;

Part A-Introduction
Part B-Topography, Bathymetry and Geological Setting
Part C-Cork Dockyard onshore area
Part D-Monkstown onshore area
Part E-Offshore estuary crossing area
Part F-References
Part G-Figures
Part H-Appendices

Supplementary data relating to the study area are contained in Appendix A.
Representative examples of the bedrock in the Cork Harbour area are presented in Appendix B.
Terminology and classification schemes used are contained in Appendix C.

PART B-TOPOGRAPHY, BATHYMETRY AND GEOLOGICAL SETTING

5-TOPOGRAPHICAL SETTING AND BATHYMETRY

The Cobh-Monkstown crossing traverses the southern end of the north-south superimposed drainage channel that cross-cuts the Great Island Anticline at Passage (Fig 1.1). The ground rises on either side of the channel to about 80m OD on Great Island and to over 100m OD north-west of Monkstown. The maximum known depth to bedrock in the channel crossing is about -36.7mOD. This occurs at the central part of the estuary crossing

The bathymetry of the area derived from the *Infomar* survey of the marine crossing is shown in Figs 1.3, 5.1 & 5.2.

The seabed elevation in the region is between c. -6mOD and -16mOD based on the *Apex* geophysical investigation (Fig 5.2).

A side scan sonar survey of the seabed has been carried out by *Aquafact International Services.*

6-REGIONAL GEOLOGICAL SETTING

6.1-Regional Bedrock Stratigraphical/Lithological Succession

The bedrock in the Cork Harbour area consists of a thick succession of Late Devonian and Early Carboniferous sedimentary rocks that accumulated in a large sedimentary basin. These rocks have undergone low-grade metamorphism and extensive structural deformation due to tectonic forces that have resulted in intense folding and fracturing of the rock layers. The structural geology of the region is characterised by large-scale ENE-WSW orientated folds. The Cobh-Monkstown estuary crossing lies on the southern limb of one of these structures, the Great Island Anticline (Fig 6.1).

The sedimentary succession in the general area of Cork Lower Harbour consists of eleven litho-stratigraphical units. However, not all of these are present along the line of the crossing due to structural reasons. A model for the structure and outcrop/subcrop of these units has been constructed for this report. This is shown in Figs 6.2, 7.1 & 13.1.

The bedrock stratigraphical succession in the area consists of the following units commencing with the oldest and finishing with the youngest, i.e. proceeding stratigraphically upwards from oldest to youngest;

BS-Ballytrasna Formation*
The bulk of the formation is composed of red to purple mudstones and similarly coloured fine to medium grained siltstones and sandstones.

GY-Gyleen Formation
This is characterised by regularly alternating mudstones and fine to medium grained siltstones and sandstones. In general, the mudstones and siltstones are of similar composition and appearance to those in the underlying Ballytrasna Formation. The sandstones are usually shades of green and grey. Sandstones occur in units up to c.10m in thickness while the mudstones and siltstones are generally red to purple and range up to about 20m in thickness.

GYbn-Gyleen Formation Ballyknock Member
This is characterised by rapidly alternating green and grey, fine to medium-grained siltstones and sandstones.

OH-Old Head Sandstone Formation
This is distinguished by the presence of well-bedded heterolithic rocks. These range from sandstone-dominated (flaser-bedded heterolithics), equally proportioned sandstone and siltstones (wavy-bedded heterolithics) to siltstone dominated (linsen-bedded heterolithics) heterolithics. Typically, the formation is grey coloured where fresh and the sediments are thinly laminated throughout.

KNcs-Kinsale Formation Castle Slate Member
This occurs as a thin (c.20m) unit of medium to dark grey siltstones and claystones.

KNcu-Kinsale Formation Cuskinny Member
This consists of alternating well-bedded grey sandstones, claystones, siltstones and heterolithic (flaser-bedded, wavy-bedded and linsen-bedded) sediments.

Typically, the heterolithics show strong lithological contrast between adjacent laminae in the Kinsale Formation. A number of thick siltstone/claystone units are present within the type section of the member at Cuskinny Bay and Ringaskiddy (Appendix A1).

At Cuskinny Bay, the composition of the member is as follows; Sandstones and Flaser-bedded Sandstones 67%, Siltstones and Linsen-bedded Siltstones 24%, Claystones 9%.

The member is subdivided into four distinct units that have been recognised in logged adjacent sections at Cuskinny Bay and Ringaskiddy (Appendix A1).

These are:

KNcu1-Sandstone dominant with minor mudstones (Claystones/Siltstones)
KNcu2-A thin c.12-15m thick grey Mudstone (Claystones/Siltstones)
KNcu3-Sandstone dominant with minor mudstones (Claystones/Siltstones)
KNcu4-Mudstone dominant with minor sandstones and flaser-bedded levels.

Units 1, 3 and 4 contain extensive heterolithic levels.

KNpc-Kinsale Formation Pigs Cove Member*
This occurs as a thin (c.20m) unit of medium to dark grey siltstones and claystones similar to that seen in the Castle Slate Member.

W-Waulsortian Limestone Formation*
This consists of pale grey to white crystalline calcareous micrite (calcareous mudstone). The rock is very competent and lacks siliciclastic sediments.

*These units outcrop outside of the area of this report.

6.2-Regional Bedrock Post-depositional Processes

This sedimentary succession has undergone a complex post-depositional, structural and diagenetic history that includes the following sequence of processes;

- Local development of syn-sedimentary faults and folds prior to lithification.
- Compaction of sediment resulting in water and gas expulsion.
- Diagenesis-Oxidation of minerals, local precipitation of carbonates and silica.
- Recrystallistion of silica/quartz etc. followed by lithification.
- Horizontal shortening took place due to forces generated by plate tectonics.
- Vertical/Subvertical, northeast-southwest orientated cleavage planes developed in fine-grained sediments.
- Large-scale gentle folds developed.
- Initially, earlier cleavage planes now began to fan or radiate with continued folding.
- Folds tightened and small parasitic folds developed.
- Thrusting, strike parallel faulting and wrench faulting developed.
- Possible reactivation of wrench faults took place later.

- Possible compartment deformation of individual fault-bounded blocks may have taken place.

- Orogen begins to be unroofed due to uplift and erosion. This resulted in a drop in the confining pressure within the rock mass that lead to the development of brittle fractures such as joints and quartz filled tension gashes.

- Mineralisation may have developed associated with hydrothermal fluid migration through joints and fractures.

- Final physical and chemical weathering took place. This would have been very intense through most of the Cenozoic (Tertiary) and Quaternary (glacial) periods.

The bedrock has endured low-grade metamorphism as a result of some of these processes.

6.3-Regional Bedrock Structure
The principal structures in the region are bedding planes, folds, cleavage planes, joints and faults.

Bedding
Bedding planes are ubiquitous. They are closely spaced in the coarser grained lithologies and less obvious in the finer-grained rocks. Bedding plane strike is generally ENE-WSW and dip is generally in excess of 45°, extending up to vertical. Dip direction is generally towards the SSE but reversals in dip are possible due to small-scale folding which is very common.

Folds
The bedding planes have been folded into a series of large-scale NE-SW trending anticlinal and synclinal fold. These are characterised by wavelengths on a scale of kilometre-size magnitude Superimposed on these large-scale structures are numerous unpredictable small-scale and medium-scale parasitic folds. Very often these show significant plunge to the north-east or south-west. The folding has resulted in steeply inclined (dipping) bedding planes being usually inclined at angles in excess of 45° throughout and strike at about 070-080°.

Prediction of the location and frequency of small to medium-scale parasitic folds is not possible.

Cleavage Fabric
Fine-grained rocks (claystones, siltstones) are strongly cleaved throughout the region with cleavage planes striking ENE-WSW. The cleavage consists of closely spaced (mm-scale) planes in which the mineral structure is aligned originally due to horizontal compression.

The cleavage planes are roughly parallel to the trend of the fold axes (c. 070°) and are inclined at angles in excess of about 80° to either NNW or SSE.

Coarser grained rocks (mostly fine- to medium-grained sandstones) contain a strong fracture cleavage that is more widely spaced than cleavage in mudstones or siltstones.

Joints
Jointing is pervasive throughout. Joint spacing ranges from cm-scale to m-scale. Joints occur in various orientations. The commonest regional orientations are between N-S and WNW-ESE.

Faults
The published geological maps of the region (19^{th} Century Geological Survey of Ireland one inch maps, Lamplugh *et al*. 1905, MacCarthy 1988, Sleeman & Pracht 1995 & Meere *et al*. 2013) show the interpreted major faults present. However, there are many smaller-scale faults orientated in various directions throughout the region. The majority of faults are either roughly parallel to the bedding strike or intersect the bedding strike at high angles.

Fault zones can vary in width from cm-scale to several metres. These may consist of (a) clean juxtaposition of fault blocks or (b) shatter zones composed of a range of fractured blocks, boulders, cobbles accompanied by quartz or other mineral veining.

Fault lines shown on the map as continuous features may in fact consist of a series of en echelon fractures of varying frequency, length, width, sinuosity and composition.

Prediction of the precise location, length, frequency and nature of shatter zones of faults is not possible in the absence of detailed field information.

6.4-Outcropping bedrock localities in adjacent areas
An illustration of the structural and lithological style from eight local onshore localities in the Cork Harbour region is contained in Appendix B. The bedrock in the estuary crossing is likely to be comparable to the corresponding stratigraphical units described in Appendix B.

In general, the structural character and lithology of the various stratigraphical units in the estuary crossing is likely to be broadly comparable to the corresponding units seen at the adjacent onshore localities on either side of the estuary. However, lateral variations in the intensity and impact of structural features, lithologies and weathering patterns are possible and unpredictable. Such variations should be expected.

PART C-CORK DOCKYARD ONSHORE AREA

7-BEDROCK GEOLOGY OF THE CORK DOCKYARD ONSHORE AREA
7.1-The Bedrock Map and Structure
The bedrock geological maps (Figs 6.2 & 7.1) constructed for this report are models of the outcrop/subcrop of the bedrock formations and structures on the rockhead based on onshore and offshore data. These are 'solid' maps that omit the superficial deposits.

The map of the Cork Dockyard area has been divided into three blocks (B1-B3) for descriptive purposes.

The boundaries between the Gyleen, Old Head and Kinsale (Castle Slate and Cuskinny Members) Formations in Blocks B2-B3 (Fig 7.1) are not known with certainty. These boundaries could be located at unknown distances to the north and/or south of their plotted position as shown in Fig 7.1. However, the boundaries along the railway line have been established by actual field observation.

The comments listed in Section 6.3 above, regarding the regional structure of the bedrock, also apply in general to the area shown in Fig 7.1.

7.2-Bedrock Stratigraphy, Lithology and Petrography

Stratigraphy

The bedrock in Fig 7.1 consists of four litho-stratigraphical units. These are; the Gyleen Formation (Ballyknock Member), the Old Head Formation, the Kinsale Formation (Castle Slate Member) and the Kinsale Formation (Cuskinny Member).

The onshore part of the estuary crossing is located within the Kinsale Formation Cuskinny Member.

Lithology

The bedrock (Kinsale Formation Cuskinny Member) is composed entirely of siliciclastic non-carbonate sedimentary rock. That comprises sandstones, claystones, siltstones and heterolithics (intricately inter-laminated sandstone/mudstones). There may also be thick (possibly up to about 15m) relatively uniform mudstone units within the succession. All of these rocks have endured tectonic deformation and low-grade metamorphism characterised by the development of a slatey cleavage in the fine-grained lithologies and a fracture cleavage in the coarser-grained lithologies.

The bulk of the sandstones are fine- to medium-grained. However, thin coarse-grained sandstones are present at a number of isolated levels. Some of these contain scattered granules and pebbles of vein quartz usually less than about 3mm grain size. Such levels have been recognised as an important stratigraphical marker facies (sediment/sedimentary structure type) in the region known as the *Garryvoe Conglomerate Facies*.

There is variation in the clay and silt content in the fine-grained rocks here. Most of the siltstones probably have between 20% and 50% clay content. They range from *Siltstone* to *Clayey Siltstone* (Appendix C2). Much of the fine-grained rocks fall into the *Silty Claystone* category. Much of what is listed as Claystone in Figs 7.3-7.12 is in fact *Silty Claystone*. There appears to be very little pure *Claystone*.

Lithological Trends

Detailed information on the lithological composition and stratigraphical position of the core taken from Boreholes RC01-DY and RC08-DY is presented in tables shown in Figs 7.3 and 7.4.

Histograms showing the lithological composition of each borehole are shown in Figs 7.5-7.14.

Composite summary logs of lithological composition of RC01-DY to RC08-DY are presented in Fig 7.15.

Lithological Trends in the Kinsale Formation Cuskinny Member
The overall lithological trend in the logged core of this member shows the following composition;

Sandstone + Flaser-bedded Sandstone-c.47%
Mudstone + Linsen-bedded Mudstones-c.23%
Weathered/Broken/Gaps-c.30%

The overall lithological trend in the logged core of the Cuskinny Member, omitting the weathered, broken and gap zones, shows the following composition;

Sandstone + Flaser-bedded Sandstone-c.67%
Mudstone + Linsen-bedded Mudstones-c.33%

The latter composition is identical to that seen at the type section of the Cuskinny Member at Cuskinny Bay on the east side of Cobh (Appendix A1) and Ringaskiddy where the lithological proportions are as follows;

Sandstone + Flaser-bedded Sandstones 67%
Mudstone + Linsen-bedded Mudstones 33%

Clearly, there is a very strong lateral lithological continuity in this member between Cuskinny Bay, Ringaskiddy and Cork dockyard. Hence, lateral lithological deviations from these figures within the Cuskinny Member along the estuary crossing would not be anticipated in the confines of the onshore dockyard area.

7.3-Planar Structures and Discontinuities
The principal planar structures/discontinuities in the area are bedding, cleavage, joint and fault planes. The orientations of bedding, cleavage and joint planes are listed in Appendices A4 and A5 and are also illustrated in strike plots (Fig 7.17) and stereographical projections (Fig 7.18).

Bedding
Bedding planes are ubiquitous in the bedrock. Their spacing ranges from cm-scale to dcm-scale (B1-Laminated through to B4-Medium Bedded). In rare cases, bedding planes may exceed 1m in separation. The intervening rock between bedding planes may be; massive (i.e. with no visible internal structures), laminated (poorly- or well-developed), cross-laminated, graded or may be internally folded.

In general, the bedding planes throughout the area, strike at about 070-083° and dip towards the SSE at angles in excess of c.40°, more usually greater that 60° (Fig 7.18, Appendix A4).

However, there are some areas where bedding planes are horizontal to gently inclined (e.g. at Ringacoltig Appendix A6). This variation is probably mainly due to localised folding and gentle frexuring of the strata. The Ringacoltig area contains several minor parasitic folds making it difficult to predict the dip and strike of beds in the area.

Cleavage

The finer grained rocks (mudstones) are strongly cleaved throughout striking at c.060-074° and inclined in excess of 80° to either the SSE or NNW (Fig 7.18, Appendix A3).

The cleavage consists of closely spaced (mm scale) planes in which the mineral structure is aligned in a particular steeply inclined orientation. This developed originally due to horizontal tectonic compression.

The cleavage planes are steeply inclined and parallel to the trend of the fold axes (c.070°).

Coarser grained rocks (sandstones) contain a strong *Fracture Cleavage* that is more widely spaced than cleavage in mudstones. Typically, this shows an anastomosing pattern (Appendix A6) in contrast to the planar form of cleavage in the finer grained lithologies.

Joints

Jointing is ubiquitous and pervasive throughout (Appendices A4-A6). Joint spacing ranges from cm-scale to m-scale. Joints occur in various orientations (Figs 7.17 & 7.18, Appendix A5). The commonest orientations in the area of the crossing are likely to be (1) between N-S and WNW-ESE and (2) ENE-WSW

Joints exhibit the following characteristics;

(1) Some joints have a curved form in plan view

(2) A small number of joints appear to be master joints that have a more regional extent than other localised joints

(3) Generally, joints tend to be more common or more prominent in sandstones than in the finer-grained lithologies. These may often terminate at the margins of sandstone units due to the different competence and ability to absorb shearing and expansion forces of the finer grained rock types.

(4) Joint spacing is likely to be broadly similar to that seen at the onshore localities (Appendix A5). Spacing shows a wide range from *Closely Spaced* to *Widely Spaced*. The following spacing categories were recorded out of forty-four outcropping joint spacing measurements;

J1-3	Closely Spaced	(<200mm)	62%
J4	Closely/Medium Spaced	(200-400mm)	36%
J5-7	Medium Spaced	(400-1000mm)	14.3%
J8-9	Widely Spaced	(>1000mm)	2.3%

The limited outcrop width in the foreshore precluded a more exhaustive survey. However, these figures are likely to be roughly representative of joint spacing in the bedrock in the region.

(5) Joints are commonly filled with crystalline vein quartz. Occasionally, very thin veins of calcite are present along joints. Joint surfaces commonly contain an iron

staining.

Other characteristics of joints (e.g. Moisture Content, Openness, Smoothness, Persistence, Waviness, Block Sizes, Block Types, Joint Patterns and Joint Plane Form) examined at outcrops are outlined in Appendix A9.

It should be noted that some of the discontinuity characteristics in the deep subsurface (i.e. at the level of the proposed tunnel) would be expected to be different than those at surface outcrops, particularly joint openness and filling. The surface bedrock would have been exposed to extensive weathering processes through the recent geological past (i.e. during the Cenozoic Period and Quaternary glacial period), in particular the effects of freezing conditions and differing groundwater circulation patterns in the shallow surface. Such conditions would not have been experienced to the same extent in the deep sub-surface leading to a difference in certain fracture characters between the shallow and deep environments.

Faults
The onshore area of the estuary crossing at Cork Dockyard is probably cut by at least one major fault (F8)(Fig 7.1). This appears to be a substantial vertical to sub-vertical fault that has been traced from adjacent areas to the south. The precise nature of the fault zone is not known. Several minor faults have been observed in the railway cutting.

The area is cross-cut by two types of fault;
(a) A NW-SE striking vertical to sub-vertical normal or wrench fault (F8).

(b) An ENE-WSW strike-orientated fault. This is possibly a high-angle reverse or thrust fault (F14).

Fault F8 is located between BH04-DY and BH05-DY. Its precise orientation is not known. The orientation shown in Figs 6.2 and 7.1 is an estimate based on regional trends.

The insertion of Fault F8 in the map is based on the following observations;
(1)There is a strong contrast in the bedding dips in the boreholes on either side of the fault shown on the maps. To the east, the dips are less than 37° while to the west they are between 64° and 80°. The contrast suggests that the easterly and westerly boreholes are located in two distinct structurally different zones. Such juxtaposition is interpreted as an indication that a bounding fault may separate the two zones and that Compartment Deformation may have been responsible for this situation. This is where adjacent fault-bounded blocks behave differently to the tectonic forces placed upon them, a situation which results in differing structural compositions in adjacent blocks.

(2) There is a strong lithological contrast between Boreholes BH04-DY and BH05-DY. This might be expected where the two areas would be separated by a fault, though the contrast is not absolutely definitive.

Faults may not be continuous structures but a composite of numerous anastomosing fractures.

On the basis of regional structural trends, it is likely that there are numerous other faults on various scales and orientations present in the estuary crossing area that cannot be predicted.

7.4-Orientation of Discontinuities in relation to the estuary crossing route
Strike information on the orientation of discontinuities in boreholes along the estuary crossing route is not available from the site investigation reports. However, substantial information on discontinuity orientation at onshore outcropping localities (Cork Dockyard-Ringacoltig-Railway cutting areas) has been recorded (Fig 7.17). It should be anticipated that a broadly similar pattern is likely to exist in the bedrock along the estuary crossing to the east of Fault F5.

If the discontinuity pattern recorded at the onshore outcrops also exists along the estuary crossing, the drawing depicting the orientation of the estuary crossing in relation to the onshore outcropping discontinuities (Fig 7.17) would give an indication of the possible angle of intersection between the orientation of the estuary crossing and that of the discontinuities in the bedrock.

Two sets of onshore outcropping discontinuities are recognised on the basis of their orientation. These are Set1 (NE-SW trend) and Set 2 (NW-SE trend). The intersection of Set 1 with the proposed estuary crossing ranges from 20-35° (mean c.27.5°). The intersection of Set 2 with the proposed estuary crossing ranges from 17°-83° (mean c.50°). The crossing route appears to cross-cut all discontinuities at various angles. The route appears not to come close to paralleling any discontinuities.

7.5-Bedrock Folding
Some parts of the onshore area contain bedding planes that are horizontal to gently inclined (e.g. at Ringacoltig Appendix A6). However, more commonly bedding planes are inclined at angles in excess of 30° due to folding of the rock layers.

Different scales of folding are present in the study area. Two large-scale folds (Syncline 1 and Anticline 1 in Fig 7.1) are identified. A number of small-scale parasitic folds are superimposed on Anticline 1 (Fig 7.1). The fold axes strike at about 070° and plunge in a south-westerly direction. The parasitic folds and shallow dipping beds make it difficult to predict the dip and strike of beds in parts of the area away from control points.

The general style of folding can be seen in Sections A-B and E-F in Fig 7.2. It is likely that the style of folding changes when traced in the west-southwesterly plunge direction. Traced from the railway cutting on the higher ground to the lower area of the dockyard, the dip of northerly inclined beds on the northern limb of Anticline 1 probably reduces significantly. This would have the effect of a both lateral and vertical south-westward architectural change from a distinct fold pair (i.e. the major anticline and syncline) in the railway section to a more gentle flexural monoclinal-like structure in this area (i.e. the dockyard area).

This monoclinal model is clearly repeated along the Ringacoltig shoreline section (Appendix A6) where the bedding is initially steeply inclined in its northern part and reduces to horizontal when traced in a southerly direction before increasing again to the south (Fig 7.2).

A monocline can be where one limb of a fold is inclined at a very low angle (c.<5°) resulting in a step-like fold in rock strata.

8-WEATHERING OF BEDROCK

A substantial proportion of the onshore DY core (c.30%) contains weathered and broken levels (NI-Non-Intact pieces) along with gaps in the record (See Figs 7.3-7.15).

About 70% of the core contains *Fresh* to *Slightly Weathered* rock.
About 30% of the core contains weathering ranging from *Moderately* to *Completely Weathered* rock.

Figs 7.3, 7.4 and 7.15 show the extent of the core that contains substantial weathered rock, broken rock fragments or gaps in the record.

Detailed records of weathering patterns from the onshore DY core are contained in the *Priority Geotechnical* Report P13097.

9-STRENGTH OF BEDROCK

The strength of the unweathered rock in the core examined ranges from *Moderately Strong to Very Strong*. The strongest rock appears to be unweathered sandstones while finer-grained lithologies tend to be weaker.

See the *Priority Geotechnical* Report P13097 for details on rock strength.

10-CORE RECOVERY AND ROCK QUALITY

10.1-Measurements of core recovery and quality

(1)A preliminary assessment of the approximate fracture pattern in the DY cores was carried out based on an examination of DY core photographs from the Official Submission dated 14th December 2015.

The thickness of intact solid core pieces (equal to or greater than 100mm) in each core box was measured and expressed as a percentage of the drilled depth of each box (i.e. RQD). The results are summarised in (Fig 10.1). These show that significant proportions of the cored bedrock have RQD values of less than 50%.

Four vertical distribution patterns of core recovery are recognised in the cored sections (Fig 10.1);
(A) RC01-DY
(B) RC02-DY and RC03-DY
(C) RC04-DY and RC07-DY
(D) RC05-DY, RC06-DY and RC08-DY

The lateral variation in the patterns of core recovery is notable.

(2)Detailed core recovery measurements are contained in the *Priority Geotechnical* Report P13097. These can be broadly summarised as follows;

	TCR	SCR	RQD
RC01-DY	85	53	40
RC02-DY	94	32	5
RC03-DY	89	45	19
RC04-DY	87	42	30
RC05-DY	90	41	16
RC06-DY	99	62	31
RC07-DY	78	57	31
RC08-DY	91	47	38

These values are average percentages for each borehole.

The *Priority Geotechnical* Report P13097 shows a consistently high Total Core Recovery (TCR) for the onshore DY core. This appears to be higher than that recorded in this report (See Figs 7.3, 7.4 and 10.1). However, the *Priority Geotechnical* Report records average RQD values are well under 50% and average SCR values are under 62%.

Boregis has prepared an indicative drill profile based on the available information. Core recovery measurements in the zone of interest (the interval between 5m above and 5m below the indicative drill profile) are as follows;

	TCR	SCR	RQD
RC01-DY	97	50	27
RC02-DY	94	47	9
RC03-DY	100	40	12
RC04-DY	100	61	47
RC05-DY	83	28	10

These values are average percentages for each borehole.

10.2-Factors influencing core recovery and quality

Apart from any influences associated with the coring process, there are several geological factors that might have an influence on the recovery/fracture patterns.

These include the following;

(1)The stratigraphical distribution of rock types. Typically, the Kinsale Formation here consists of rapidly alternating (heterolithic) coarse and fine layers (Appendix A1). The close juxtaposition of different lithologies could result in differing core recovery patterns.

(2)The DY boreholes here are probably cut through a lower stratigraphical level in the Cuskinny Member than the EC boreholes further south. This part of the member could be significantly different to that encountered in the earlier boreholes to the south.

(3)Borehole RC01-DY contains fewer distinct claystone levels and possibly more sandstone and siltstone levels. This may have contributed to the distinctively different fracture pattern in this borehole.

(4)Bedding plane density and heterolithic distribution appear to be significant factors in influencing the ‘fracture’ pattern. Many of the fractures that result in small core pieces have formed by separation along closely spaced bedding/lamination planes.

This feature is most prominent in the heterolithic levels where the rapid alternation of coarse and fine lithologies result in a strong lithological contrast across bedding plane boundaries. This would facilitate bedding/lamina separation and the formation of small core pieces resulting in low RQD values.

(5)Spatially varying weathering patterns are an important factor at several levels where evidence of heavy oxidation is present due to migrating groundwater through bedrock with secondary fracture porosity. This would have weakened the rock mass in such zones resulting in low SCR and RQD values.

(6)Locally faulted zones are likely to be present. These would contain fractured fault breccias and disrupted bedrock masses of varying thickness and distribution.

(7)Boreholes RC04-DY to RC07-DY show relatively shallow dipping beds of varying dips due to flexuring. This contrasts with the more steeply inclined bedding in Boreholes RC01-DY to RC03-DY. The hinge zones associated with the folding in the former case may contain additionally fractured bedrock due to locally enhanced extensional and compressional forces, which play a part in these zones.

(8)Jointing patterns-The intensity and extent of the jointing in the bedrock has a very strong influence on core recovery and accounts partially for the low RQD values.

(9)Faults-A major fault (F8) is predicted in the Cork dockyard area. The fault zone could contain associated fractured bedrock and subsidiary splay faults.

(10)Other factors which can potentially affect poor RQD values include; drilling techniques used, core breakage during handling, stress relief, shearing and weathering of the bedrock.

11-ROCKHEAD DEPTH

The rockhead lies close to the surface on the eastern side of the main road. The rockhead in the dockyard site gradually descends in a westerly direction from about -1.3mOD at BH06-DY to -13.3mOD at BH01-DY (Fig 11.1).

12-SUPERFICIAL DEPOSITS

12.1. Thickness of superficial deposits

Information on the thickness of the superficial deposits is summarised in Fig 12.1. In general, the deposits thicken southwards and westwards across the onshore area.

12.2-Superficial deposits in onshore boreholes

These consist of Boreholes BH01-DY to BH08-DY and BH16-CH, BH17-CH, BH102-CH and BH103-CH.

Boreholes BH16-CH, BH17-CH, BH102-CH and BH103-CH

Information on the composition and distribution of the superficial deposits in these boreholes is summarised in Fig 7.16.

See *PGL Priority Geotechnical* report P13097 dated 22nd January 2015.

The boreholes are dominated by alternating Silty and Sandy Gravels with variable amounts of Sandy Gravelly Silt. ‘Boulders’ and ‘Boulder Clay’ are present in BH16-CH.

Boreholes BH01-DY to BH08-DY
Information on the composition of the superficial deposits is summarised in Fig 12.1.

See *PGL Priority Geotechnical* P13097 report dated 12th November 2015.

The vertical and lateral distribution pattern of these deposits is illustrated in Fig 12.2.

The borehole records for BH01-DY do not appear to contain sufficient information on the superficial deposits for inclusion in Fig 12.1. Consequently, it is not clear to what extent the superficial formations in the adjacent boreholes extend into the area of BH01-DY.

The deposits are dominated by multi-coloured (grey, red, brown), medium dense, clayey and sandy gravels with a high cobble content, silts and clays.

The full borehole record in the east (BH07-DY) is dominated by gravels. Traced westwards, the Gravel formation bifurcates into (1) a lower layer that persists only as far BH03-DY and (2) an upper layer that extends at least as far as BH02-DY (Fig 12.2).

The intervening sequence between the two Gravel layers consists of Clays and Silts.

The lower Gravel layer dies out when traced southwards towards BH08-DY.

A laterally impersistent Silt layer underlies the upper Gravel layer. This is thickest in BH02-DY and BH08-DY.

Traced south-westwards from BH07-DY towards BH102-CH, the gravel-dominated sequence appears to show an increase in finer sediment grades which probably form a matrix to the gravels. This finer unit contains; Sandy silty gravels, Sandy gravelly silts, Silty sandy gravels and Slightly silty gravels.

It is likely that the gravels and possibly the sands are porous and permeable.

PART D-MONKSTOWN ONSHORE AREA

13-ONSHORE BEDROCK AND SUPERFICIAL DEPOSITS MONKSTOWN AREA

Bedrock is exposed at three principal locations in the Monkstown area (Figs 6.2 & 13.1a & 13.1b). These are;
(1) Passage Road-roadside outcrop (Ballytrasna Formation and Gyleen Formation)

(2) Glen Road Quarry-an old quarry behind housing (Gyleen Formation)
(3) Raffeen Road-coastal outcrops (Old Head Formation).

The bedding throughout appears to be inclined steeply to the SSE.

13.1-Passage Road-roadside outcrop
The bedrock here is dominated by purple mudstones (mostly siltstones) and fine-grained sandstones of the Ballytrasna Formation. These sediments are thinly-bedded to thickly-bedded and are internally laminated or locally massive. The rock types are similar to Facies 2 and 3 described below in the Gyleen Formation (Figs 13.2, 13.3 & 13.23).

The typical basal non-purple grey-green beds of the overlying Gyleen Formation can be seen at the southerly end of the roadside outcrop. The beds here are strongly cleaved and jointed.

13.2-Glen Road Quarry
The upper part of the Gyleen Formation is well exposed at the Glen Road Quarry, Monkstown where a continuous bedrock section is exposed measuring c.100m in length (Figs 13.1a & 13.1b, 13.4 & 13.24). A comparative representative log of the formation at Weaver's Point south of Crosshaven is contained in Appendix B10. This shows a very regular alternation of coarse- and fine-grained lithologies with thick mudstone units alternating with relatively thin sandstones. The formation in the Monkstown area corresponds to the upper part of the formation and consists of a similar alternation of rock assemblages or *facies*. These are;

Facies 1-Relatively thin (c.1-3m) pale green, grey and greenish grey medium-grained laminated and thinly bedded sandstones and siltstones. This forms a minor component of the formation (c.10-15%).

Facies 2-Thick (c.2-5m) pale red to pale purple fine-grained well-bedded laminated sandstones and siltstones. This constitutes about 60-70% of the formation.

Facies 3-Thick (possibly up to c.10m+) pale red to pale purple siltstones with minor fine-grained thinly laminated or massive sandstones and claystones. This forms about 10-20% of the formation.

These are illustrated in Figs 13.5 to 13.18. A schematic log of the formation at Glen Road Quarry is shown in Fig 13.24.

Importantly, the rock types present in the Gyleen Formation are similar to those of the Ballyknock Member of the same formation (Compare lithological/sedimentological logs of these units exposed near Weaver's Point, south of Crosshaven-Appendix B10 and B13). However, the proportion of sandstone is much greater in the Ballyknock Member than in the underlying Gyleen Formation.

Consequently, the rock types and structures visible at the Glen Road Quarry can be regarded as being broadly similar to what might be encountered in the estuary crossing in Blocks B4 and B5 where the offshore estuary crossing may intersect the Ballyknock Member (Gyleen Formation) (Figs 13.1a & 13.1b).

13.3-Raffeen Road
This coastal outcrop is poorly exposed. It consists of thinly-bedded, laminated grey brown, fine to medium-bedded sandstones and poorly formed flaser-bedded and linsen-bedded sediments. The beds here are steeply inclined and overturned to the south possibly as a result of glacial processes. These rock types are thought to belong to the Old Head Formation though this would need to be confirmed by age dating analysis.

13.4-Planar Structures, Discontinuities and Mineralisation
Bedding, cleavage and joint planes are ubiquitous in the onshore Monkstwon area. Faults are apparently sparse.

Bedding
Bedding planes in the three localities strike at c.070° and are generally steeply dipping (45-80°) to the SSE. The bedrock is thinly to medium bedded.

The upper part (up to 2-3m) of the bedrock at all localities has been overturned due to mass movement associated with soil creep and or post-glacial permafrost freeze/thaw processes.

Cleavage
Cleavage is strongly developed throughout all the outcrops (Figs 13.2-13.19). This is closely spaced in the finer lithologies and more widely spaced in sandstones.

Joints
The bedrock is strongly and intensely jointed (Figs 13.2-13.19). Frequently, these joints contain significant amounts of vein quartz infillings. This is particular notable where joints traverse sandstone units (Facies 1) (Figs 13.17-13.19).

Faults
Four faults have been identified along the 100m length of Glen Road Quarry that was examined (Figs 13.6, 13.8, 13.12-13.15). Three of these are relatively tight structures with minimal fault width measuring less than c100mm. One fault (Figs 13.12-13.14) appears to be filled with a (c.300mm thick) clay-grade possible fault gouge. Minor faults of these types are typical of this region.

Of the four faults, only one shows a NNW-SSE strike and is sub-vertical. The remainder are parallel to the bedding strike and are inclined at the same angle or close to the bedding. These strike-faults are thrust-faults, which resulted in layer-parallel shortening or telescoping of the beds during the initial phases of northerly directed tectonic deformation prior to actual folding of the beds.

See Section 14.5 below in relation to the structural interpretation of the bedrock in the Sand Quay area, Monkstown.

Mineralisation
The only mineralisation noted is the occurrences of vein quartz, which forms infills to some joints and faults. Typically, this occurs as relatively thin (<100mm) zones as joint or fault infillings. Vein quartz is more common in sandstone beds. These are

usually confined to the sandstone body and wedge out over shore distances.

13.5-Orientation of Discontinuities

The orientations of adjacent onshore bedding, cleavage and joint planes are listed in Appendix A4 and are also illustrated in strike plots (Figs 13.20 & 13.21) and stereographical projections. Joint orientations in the onshore area range from NW-SE to NNE-SSW

13.6-Onshore PM Boreholes Bedrock

The following onshore boreholes at Monkstown (*Priority Geotechnical Ltd.* Report No. 13101) are reviewed here; BH001PM, BH026-PM, RC026-PM, BH031-PM, RC031-PM, BH032-PM, RC032PM, BH033X-PM, RC033X-PM.

A summary stratigraphical correlation based on this report was constructed to illustrate the spatial relationships of the sediments in the onshore boreholes (Fig 13.22).

The Onshore Bedrock

The detailed information on lithologies, fractures and discontinuities in italics below is derived from the *Priority Geotechnical* borehole logs.

RC026-PM

-13.31 to -27.71mOD

Weak to medium strong, light green/ grey, thinly bedded, fine-grained SANDSTONE with interbedded SILTSTONE, quartz veining and pyrite crystals.

Weathering: Slightly weathered. Clay smearing. Slight discoloration along fracture planes. Oxide staining.

Fractures: Closely spaced. Fractures dip 30-45 degrees with planar smooth surfaces.
15.6m - 16.6m: Fracture index - NI.
16.6m - 17.8m: Fracture index - NI.
17.8m - 19.3m: Fracture index - 14.
19.3m - 20.8m: Fracture index - 4.
20.8m - 22.0m: Fracture index - 10.
22.0m - 23.5m: Fracture index - 14.
23.5m - 25.0m: Fracture index - 2.
25.0m - 26.5m: Fracture index - 4.
26.5m - 28.0m: Fracture index - 5.
28.0m - 29.0m: Fracture index - 8.
29.0m - 30.0m: Fracture index - 6.

Core recovery measurements in the zone of interest in RC026-PM are as follows;

	TCR	**SCR**	**RQD**
RC026-PM	57	28	11

RC031-PM

1.47 to -11.43mOD

Weak to strong, grey/ brown, thinly bedded SILTSTONE with thin beds of sandstone and quartz veining.

Weathering: Slightly weathered. Orange/ brown oxide staining. Minor loss of strength.

Fractures: Closely to medium spaced.
Fractures dip approximately 40-60 degrees with
planar and rough surfaces.
2.1m - 3.3m: Fracture index - 12.
3.3m - 4.6m: Fracture index - 12.
4.6m - 6.1m: Fracture index - 15.
6.1m - 7.2m: Fracture index - 8.
7.2m - 8.2m: Fracture index - 9.
8.2m - 9.7m: Fracture index - 8.
9.7m - 11.2m: Fracture index - 10.
11.2m - 12.7m: Fracture index - 11.
12.7m - 14.0m: Fracture index - 9.
14.0m - 15.0m: Fracture index - 6.

RC032-EC
-4.45 to-11.15mOD
Weak to medium strong, grey/ green SANDSTONE.

Weathering: Slightly weathered. Clay infilling. Brown oxide staining.
Fractures: Closely spaced. Fractures dip 30-45 degrees with planar smooth surfaces.
7.5m - 7.6m: Non-intact.
7.5m - 9.0m: Fracture index - 2.
8.5m - 10.5m: Non-intact.
10.5m: Fracture index - 2.
10.5m - 11.9m: Fracture index - 11.
11.9m -12.7m: Fracture index - 7.
12.7m - 14.2m: Fracture index - 4.
13.5m - 14.2m: Non-intact.

-11.15 to -14.15
No recovery

-14.15 to -16.95mOD
Weak to medium strong, grey/ green SANDSTONE.

Weathering: Highly weathered. Clay infilling. Brown oxide staining. Loss of strength.

Fractures: Closely spaced. Fractures dip 30-45 degrees with planar smooth surfaces.
17.2m - 18.4m: Non-intact.
17.2m - 18.7m: Fracture index - 2.
18.7m - 20.0m: Fracture index

RC033X-PM
0.27mOD to -6.28mOD
Weak, purple, thinly laminated MUDSTONE.

Weathering: Slightly weathered. Localised discoloration.

Fractures: Closely spaced.
Fractures dip approximately 50-70 degrees with planar smooth surfaces.
5.7m - 5.87m: Non-intact.
5.7m - 7.2m: Fracture index - 3.
6.33m - 6.67m: Non-intact.
7.2m - 8.6m: Fracture index - 5.
8.6m -10.1m: Fracture index - 4.

-6.28 to -9.03mOD

Weak, light green/ grey, thinly laminated SILTSTONE with quartz veining.
Weathering: Slightly weathered. Localised discoloration.

Fractures: Closely spaced. Fractures dip approximately 50-70 degrees with planar smooth surfaces.
13.2m -14.7m: Fracture index - 5.
14.7m -15.0m: Fracture index - 1.

Conclusions

The bedrock appears to be part of the Gyleen Formation though it is not certain whether it is the upper Gyleen Formation or the lower Ballyknock Member of the same formation. It is composed of purple thinly laminated mudstones, green grey thinly laminated siltstones, grey green sandstones and siltstones.

A good example of the general type of bedrock in the location of these boreholes can be seen at outcrops in Glen Road Quarry, Monkstown (Figs 13.4-13.19). The fracture pattern as seen in these rock outcrops can be expected to be also present in the bedrock beneath the playground and extending to the Sand Quay. However, weathering patterns could vary between the two areas.

13.7-Onshore PM Boreholes Superficial Deposits

The *PGL Priority* Report (No. 13101) states that *'the site is predominantly characterised by deposits of very soft to stiff slightly sandy (slightly) gravelly CLAY/ SILT, silty gravelly SAND and loose to dense clayey/ silty (very) sandy GRAVEL with low to high Cobble content and Boulder content to depths up to 19.0m bgl'.*

The distribution of these sediments is shown in Figs 13.22, 16.2 & 16.3. Gravels occur exclusively resting on the bedrock in the most proximal borehole (BH033X-PM). These appear to thin and grade laterally to siltstones when traced eastwards, i.e. in the apparent original drainage direction. The form of the bedrock is obviously a factor in influencing the architecture of these deposits here. Gravels again appear at the base of the unconsolidated deposits at BH026-PM, which is the most easterly onshore borehole. Gravels are absent from BH001-PM Monkstown Sand Quay.

It is likely that the gravels seen in the boreholes were deposited by fluvial outwash systems related to melting ice at the end of the last glacial period. These would have discharged large volumes of sediment-laden water through Monkstown Glen depositing gravels and sand in the area of the playground.

13.8-Boregis Report summary of PGL and Minerex Reports

The results of the *PGL Priority* report were summarised in the *Boregis* report as follows.

Boreholes

PGL Priority investigated the ground conditions at Monkstown. The Report for this work, "Cork Lower Harbour Main Drainage Scheme, Passage West & Monkstown Collection Network - Site Investigation - No. P13101", dated 11/04/2014, has been reviewed. An interpretive report related to this study was also produced by PGL Priority and is dated 04/07/2014.

BH026-PM *encountered sandy SILT or silty GRAVEL down to 15m depth (water strike at 14m in gravel rose to 3m in 20 minutes). SPT's in the silt were all 5 or less and in the gravel rose above 50 at 15m depth.*

Coring below the gravel was in SANDSTONE interbedded with SILTSTONE. RQD's were variable from 0 to 60 down to 30m total depth. The interface with the bedrock is recorded at -12.91m elevation.

Boreholes 031 through 033 were located within the playground car park and on the lower portion of Glen Road at Monkstown. These provide data relevant to the exit portion of the proposed drilling works.

BH031-PM *at the Car Park (southerly side) had only 1.9m depth of SILT and GRAVEL with medium cobble content overburden above the reported bedrock elevation of +1.67m, which was categorised as being thinly bedded SILTSTONE with thin beds of sandstone. RQD's were variable 19 to 77 down to 15m depth. Dip angle 40 to 60 degrees. UCS of tested sample at 11.8m depth was low at 16.47MPa. Tensile strength 1.35 MPa*

BH032-PM *also at the car park, had 7m depth of overburden above the bedrock consisting of GRAVEL overlying sandy SILT overlying further GRAVEL with medium cobble content. Water encountered in the lower gravel rose to 2m depth in 20 mins suggesting the silt is fairly impervious. The silt has less than 10% clay and 60% sand. The bedrock below from -4.25m elevation was categorised as being SANDSTONE. RQD's variable 0 to 71 down to 20m depth. Fractures dip 30 - 45 degrees.*

BH033X-PM *located on Glen Road had 5m depth of overburden above the rock consisting of GRAVEL with medium cobble content. Bedrock below from +2.7m elevation being MUDSTONE to 12m depth then SILTSTONE below to 15m depth. RQD's variable 40 to 79 (plus a zero value at the bottom of the hole). Dip 50-70 degrees. Mudstone UCS 7.37MPa, Tensile 3.53 MPa.*

Groundwater and Bedrock

All borings report that groundwater was not encountered, however this may be misleading, especially as there was one report of "blowing" conditions in the gravel material in BH09-EC.

Packer tests undertaken in the bedrock give permeability values consistent with a highly fracture rock mass.

The borings at Monkstown confirm that the granular GRAVEL material, lying generally above the bedrock across the whole site, is likely to be highly permeable and the overlying silt may retain an artesian pressure from this lower gravel level.

The bedrock is generally anticipated to present lower permeability, however highly fractured material may give up much more water readily when exposed.

The results of a *Minerex* report were summarised in the *Boregis* report as follows.

The geophysical survey undertaken by Minerex Geophysics suggests that the bedrock possibly drops away in steps down the original alignment of the water-course and that in the vicinity of Sand Quay the bedrock elevation is at around -15m elevation, a little deeper than indicated by BH026. The overburden depth in BH's 031 and 033 suggest that the original width of the now infilled water-course channel may have been quite narrow.

PART E-OFFSHORE ESTUARY CROSSING AREA

14-GEOLOGY OF THE OFFSHORE ESTUARY CROSSING AREA

14.1-Introduction

The general comments listed in Section 6.3 above, regarding the regional structure of the bedrock, also apply to the offshore estuary crossing area.

Detailed information on the bedrock geology of the estuary crossing has been provided by borehole core RC01-EC2 to RC07-EC2 and core from BH04-EC to

BH09-EC (Figs 13.1a & 13.1b). Figs 14.1-14.3 contain summary tabular information on the lithological composition, stratigraphical levels, weathering and discontinuities in these boreholes. Lithological composition is also summarised as histograms in Figs 14.4 to 14.11.

The bedrock in the immediate area of the crossing consists of four stratigraphical units. These are; the Gyleen Formation, Gyleen Formation (Ballyknock Member), the Kinsale Formation (Castle Slate Member), the Kinsale Formation (Cuskinny Member). These have been mapped extensively in the onshore region where their characteristics have been well established and have been identified in the core material extracted from the above boreholes.

The location of the stratigraphical boundaries in the offshore area of Blocks B3-B5 are uncertain between the boreholes. These boundaries could be located to the north and/or south of their plotted position as shown in the geological map (Figs 13.1a & 13.1b).

The area is traversed by at least one important major fault (F5). There is uncertainty as to whether a second major fault (F4) is present. Other uncharted faults may be present in the area.

The bedrock geology of the offshore part of the estuary crossing is considered in two parts;

(1) The area to the east of Fault F5-Block B3
(2) The area to the west of Fault F5-Blocks B4 and B5

14.2-The area to the east of Fault F5-Block B3

The character of the bedrock in the offshore area between Fault F5 and Cork Dockyard (Block B3) is likely to be similar to that in the onshore Cork Dockyard area described in Part C above. The bedrock in this area consists of the Castle Slate and Cuskinny Members of the Kinsale Formation.

The bedrock in this area is composed almost entirely (c.99%) of siliciclastic non-carbonate (i.e. non-limestone) sedimentary rock. These comprise mudstones (claystones and siltstones), sandstones and heterolithics (intricately interlaminated sandstone and mudstone). The remainder are thin weakly calcareous zones and veins that owe their origin to late circulation of calcareous fluids through the rock. There are no limestones in the area. All of these rocks have endured low-grade metamorphism characterised by the development of a slatey cleavage. See Section 15.3 below for details of the petrographical composition of the bedrock.

Kinsale Formation Castle Slate Member

This occurs as a thin (up to 30m) unit of medium to dark grey siltstones and claystones. The rock is strongly cleaved. A thin section of this unit is thought to be present in RC04-EC2 (Figs 13.1a & 13.1b, 14.2, 14.7 & 14.11) where it is thought to be in fault contact with the Ballyknock Member.

Kinsale Formation Cuskinny Member

The lithologies that compose the Cuskinny Member in the onshore Cork Dockyard area have already been described in Part C Section 7.2 above. These descriptions also apply in a general way to the member in the offshore area from the Cork Dockyard as far westward as Fault F5. There may also be a thin relatively uniform mudstone unit (KNcu2 - c.12-15m thick grey mudstone) within the succession.

The Cuskinny Member is present in RC05-EC2 to RC07-EC2 and consists of a high proportion of fine to medium-grained sandstones and flaser-bedded sandstones (Figs 14.8-14.11). The lithological composition of RC05-EC2 and RC06-EC2 are comparable. This contrast is partly due to variations in the proportion of flaser-bedded levels between the two locations. The upper part of RC05-EC2 may be equivalent to the lower part of RC06-EC2. RC07-EC2 is almost entirely dominated by sandstones. It is likely that this borehole is stratigraphically well above the top of RC06-EC2.

14.3-The area to the west of Fault F5-Blocks B4 and B5

The character of the bedrock in the offshore area to the west of Fault F5 (Blocks B4 and B5) is likely to be broadly similar to that in the onshore Monkstown area described in Part D above. The bedrock here consists of the Gyleen Formation and the Gyleen Formation Ballyknock Member. The boundary between these units appears to lie between boreholes BH01-EC2 and BH02-EC2 (Figs 13.1a & 13.1b).

Gyleen Formation

This formation is well exposed at Glen Road Quarry (See Section 13 above). The succession intersected in Borehole BH01-EC2 is comparable to that exposed in Glen Road Quarry (Figs 13.24, 14.4 & 14.11). The formation consists of distinctive cyclic alternation of lithologies. These consist of erosively-based greenish grey sandstones that fine upwards to thick red and purple fine-grained sandstones and siltstones.

The lithologies and structures in this formation in the offshore area are anticipated to be similar to those seen at the onshore outcrops.

Gyleen Formation Ballyknock Member

This member is not exposed at any of the immediate onshore bedrock exposures. However, there is good exposure of the unit at Cuskinny Bay and Weaver's Point where it is characterised by alternating greenish, yellowish, purple and red laminated and massive siltstones and fine- to medium-grained sandstones (see Appendix B13 & B14).

The member has been intersected by several offshore boreholes in Block B4 (BH02-EC2, BH03-EC2 (Figs 13.1ab, 14.1, 14.5, 14.6 & 14.11). These contain bedrock that bears all the characteristics of the outcropping Ballyknock Member. The core from these boreholes is exactly as mapped on coastal sections. Importantly, red and purple siltstones and fine-grained sandstones are present in the core, which is a clear indication of their stratigraphical level.

Borehole BH07-EC has also provided information in Block B4. This penetrated a significant depth of the member where it consists of the following rock types;

-15.1-41mOD

Weak (along bedding planes) to occasionally medium strong grey to dark grey occasionally dark red thinly bedded fine to medium grained SANDSTONE and thinly *laminated fine-grained SILTSTONE.*

-41.00-50.35mOD
Medium strong to strong grey thinly laminated to thinly bedded fine to medium grained SANDSTONE interbedded with fine to medium grained mudstone and siltstone intraclasts.

As mentioned above, the rock types and structures in this member are broadly similar to those seen in the Gyleen Formation exposed at Glen Road Quarry, Monkstown. The principal differences between this and the Ballyknock Member are the proportion of sandstones present and the vertical organisation of lithologies in the succession.

14.4-Bedrock Structure, Discontinuities and Mineralisation in the offshore estuary crossing area

The principal planar structures/discontinuities in the area of the crossing are bedding, cleavage, joint and fault planes.

The orientations of adjacent onshore bedding, cleavage and joint planes in the Cork Dockyard area (Figs 7.17 & 7.1) would be expected to continue into the offshore area of Block B3

The orientations of adjacent onshore bedding, cleavage and joint planes in the Monkstown area (Figs 13.20 & 3.21) would be expected to continue into the offshore area of Blocks B4 and B5.

Bedding

In general, the bedding planes throughout the offshore crossing area probably strike at between 060° and 080° (mean of 070°) and dip at angles of about 10-90° (Figs 14.1-14.3).

The direction of dip of bedding planes is not known and hence the fundamental structural framework of the bedrock here is not known with certainty.

The bedding dip direction could be interpreted as being broadly similar to that seen in the adjacent onshore areas, i.e. towards the SSE. However, this is the simplest interpretation and may not be either fully or partially correct.

There may be some areas where bedding planes are horizontal to gently inclined (e.g. at Ringacoltig Appendix A6) as suggested by the range of dip recordings in the offshore boreholes. These variations are probably mainly due to localised folding and flexuring of the strata.

<u>It is highly likely that the bedding is undulating and that a number of open folds and/or monoclinal structures are present in Blocks B3 and B4 as seen in Blocks B1 and B2 (Fig 7.2). The axes of such folds would strike at about 070</u>°.

Cleavage

The finer grained rocks (mudstones and siltstones) are strongly cleaved throughout striking at c.070° and inclined in excess of 80° either to either the SSE and/or NNW. The mudstones of the Gyleen Formation, including the Ballyknock Member, are expected to be strongly cleaved.

Coarser grained rocks (sandstones) contain a strong fracture cleavage that is more widely spaced than cleavage planes in mudstones or siltstones. Typically, this shows an anastomosing pattern (Appendix A6) in contrast to the planar form of cleavage in the finer grained lithologies (Appendix A6).

Joints

Jointing is ubiquitous and pervasive throughout. These are usually steeply inclined though low angles are also present (Figs 14.1-14.3). Joint spacing ranges from cm-scale to m-scale. Joint orientations are expected to be similar to those in the adjacent onshore areas ranging from NW-SE to NNE-SSW (Figs 7.17, 13.20, 13.21 & 14.1-14.3). Joint surfaces are commonly iron stained and contain quartz and possibly minor calcite veins.

Faulting/folding in the estuary crossing

The estuary crossing area is cut by at least one major fault (F5, Fig 13.1ab). This is a substantial steeply dipping fault that has been identified in Borehole BH04-EC2 (Fig 14.7). The fault has been traced from adjacent areas and is also predicted on the basis of the substantial horizontal offset (c.350m) of stratigraphical units across the estuary. The actual direction of relative movement across the fault is not known.

The geological map (Figs 13.1a & 13.1b) shows that the succession to the east of Fault F5 has been displaced dextrally by about 350m horizontally in relation to the bedrock on its west side. This has resulted in the juxtaposition of the Castle Slate and Ballyknock Members in the area of the crossing.

In vertical section, Borehole BH04-EC2 contains what appears to be the Castle Slate Member in its upper part. The Castle Slate Member is characterized by strongly cleaved, dark grey siltstones and claystones. This passes downwards into a sequence that is clearly Ballyknock Member (based on its lithological and sedimentological characteristics).

The contact zone between the two contrasting units in this borehole is characterized by strongly brecciated and shattered bedrock that extends intermittently for 17.7m vertically. The actual contact level is characterized by quartz veining. All of this indicates that the contact zone between the Castle Slate and the Ballyknock Member in this borehole is the site of a significant fault that is interpreted as the major fault F5. This fault separates the eastern part of the crossing containing the Cuskinny Member from the western part containing the Gyleen Formation. Such a fault would be expected to contain extensive shattering and brecciation of the bedrock along with the development of potentially numerous minor anastomosing parallel and sub-parallel fractures and faults.

The simplest interpretation of the structural framework is that Fault F5 is inclined at a high angle to the east. This situation would result in the vertical juxtaposition of the Castle Slate and the Ballyknock Members. These units would normally be stratigraphically separated by over 300m from each other. The interpretation therefore suggests that Borehole BH04-EC2 actually intersects Fault F5.

Bedding plane dips/inclinations across the offshore area suggest that the bedrock is probably extensively folded. The style of folding is likely to be comparable to that seen in Blocks B1 and B2 (see cross-sections A-B and E-F in Fig 7.2).

14.5-The Bedrock Structure in the Sand Quay area

There is uncertainty as to how to explain the apparent statigraphical boundary pattern between the Gyleen Formation and the Ballyknock Member in the Sand Quay area, Monkstown.

Two basic structural models (Models 1-2) are proposed (Figs 13.1a and 13.1b). A third model (Model 3) is a combination of Models 1 and 2.

Model 1

This interprets the outcrop/subcrop stratigraphical boundary pattern by recognising a fault (Fault F4) crossing the area close to the Sand Quay (Fig 13.1a). The available borehole information suggests that the bedrock in Boreholes BH001-PM, BH026-PM, BH031-PM and BH033X may represent the Ballyknock Member (Gyleen Formation). If correct, a fault would possibly be required to explain the boundary offset between the onshore and offshore areas here. There is uncertainty about the character, orientation and exact location of such a fault.

Model 2

Alternatively, the stratigraphical offset could be explained by invoking a south-westerly plunging fold system that would allow the boundary to follow a sinuous form across the apparent offset (Fig 13.1b). Such fold systems are well known in this region.

Model 3

This would involve a combination of both Models 1 and 2.

<u>The three models are of equal standing, i.e. there is no preference as to which of these models might represent the actual bedrock structure and outcrop/subcrop pattern.</u>

It should be noted that the remaining areas between these faults/folds would be expected to contain several other minor faults of varying orientation and character.

Mineralisation

Vein mineralisation similar to that seen in the onshore outcrops (Figs 13.13-13.19) should be anticipated in the offshore area. Veins consisting mostly of quartz are common particularly in sandstones. Minor veins are composed of calcite.

The unexpected and unlikely occurrence of small-scale mineralised bodies or intrusions in the offshore estuary area possibly associated with faulted zones cannot be ruled out in the absence of a detailed geophysical survey and site investigation of the area. Several local mineralised bodies occur in County Cork. Interestingly, a small (3.5km long by 100m wide) dolerite/gabbro igneous intrusion outcrops near Bandon. It would not be geologically impossible for such intrusions to have occurred elsewhere in this region.

14.6-Weathering of Bedrock

A substantial proportion of the offshore EC2 core contains weathered and broken levels (NI-Non-Intact pieces) along with gaps in the record (See Figs 14.1-14.10).

About 70% of the core contains *Fresh* to *Slightly Weathered* rock.
About 30% of the core contains weathering ranging from *Moderately* to *Highly Weathered* rock (see *Priority Geotechnical* borehole records for details-Sections 16 and 17 below).

14.7-Strength of Bedrock
The strength of the unweathered rock in the core examined ranges from *Moderately Strong to Very Strong*. The strongest rock appears to be unweathered sandstones while finer-grained lithologies tend to be weaker (see *Priority Geotechnical* borehole records for details-Sections 16 and 17 below).

15-CORE RECOVERY AND ROCK QUALITY
15.1-Measurement of core recovery and quality
Core recovery data were recorded in the *Priority Geotechnical* core logs (dated June 2016). This includes Total Core Recovery (TCR), Solid Core Recovery (SCR) and Rock Quality Designation (RQD) data.

The results can be broadly summarised as follows;

	TCR	**SCR**	**RQD**
RC01-EC2	96	40	12
RC02-EC2	100	59	26
RC03-EC2	100	57	19
RC04-EC2	89	41	14
RC05-EC2	90	53	28
RC06-EC2	93	71	56
RC07-EC2	99	63	34

These values are average percentages for each borehole.

Average TCR values are consistently high in all seven EC2 boreholes with relatively minor low values (Fig 15.1).

Average SCR values range from 40 to 71%.

Average RQD values are notably low (12-34%) in six of the seven boreholes examined (Fig 15.1).

Core recovery measurements in the zone of interest (interval between 5m above and 5m below the indicative drill profile) are as follows;

	TCR	**SCR**	**RQD**
RC01-EC2	85	46	6
RC02-EC2	99	53	26
RC03-EC2	100	68	23
RC04-EC2	95	49	9
RC05-EC2	100	66	30

RC06-EC2	98	83	76
RC07-EC2	95	65	56

Core recovery values for the offshore EC2 core in the drill zone of interest show consistently high average Total Core Recovery (TCR) of 96%. Average SCR values are 61% while average RQD values are 32%.

A broad pattern of RQD values is recognised across the estuary crossing. This is illustrated in Fig 15.2, which shows that values in excess of 50% tend to occur in the lower part of the boreholes in the eastern side of the crossing (RC05-EC2 to RC07-EC2) and in RC03-EC2. This pattern diminishes towards the west where the majority of the boreholes are characterised by RQD’s of well under 50% (Fig 15.2).

The high RQD values to the east (RC05-EC2 to RC07-EC2) appear to correspond with the Cuskinny Member. However, the upper parts of these boreholes that contain this member show very low RQD values. Hence, lithological factors alone are not responsible for the rock quality patterns.

Notably, adjacent boreholes in the same rock formation containing similar lithological content and structural architecture show limited correlation of rock quality parameters.

15.2-Factors influencing core recovery and quality
Factors that may have influenced core recovery and rock quality are listed in Section 10.1 above. Key bedrock factors that have played an important part in rock quality include; stratigraphical (lithologies, sedimentary structures including bedding planes) and deformational characteristics (folding, cleavage, joints and fault planes). Weathering processes have also played an important part in the post-deformational history of the rock mass.

16-CORE IN OFFSHORE ESTUARY EC BOREHOLES
16.1-Examination of core from Boreholes BH04-EC, BH05-EC, BH06-EC, BH07-EC, BH08-EC, BH09-EC and RC102-EC

Examination of selected core from parts of RC04-EC, RO06-EC, RC07-EC and RC08-EC was carried out on the 7th April 2015 and the 12th June 2015 by the author.

The core was examined for information on lithology and various geological structures. See Appendix A3 for detailed notes on the core that was examined on these occasions.

16.2-Summary Description of borehole records and Conclusions
The following offshore boreholes are reviewed in this section; BH04-EC, BH05-EC, BH06-EC, BH07-EC, BH08-EC, BH09-EC and RC102-EC.

Causeway Geotech borehole logs (Report 13-381 dated June 2015) should be viewed in conjunction with this report.

Information on lithologies and discontinuities in italics below is derived from the *Causeway Geotech* borehole logs.

Apart from the core that was examined, information in the **Conclusion** sections below on bedding dip amounts are estimates made by examination of photographs of the core from the site investigation reports. These estimates assume that the boreholes were vertical.

BH04-EC

21.15-27.85m

Lithology: *Very weak to weak grey occasionally brown and grey thinly laminated to thinly bedded fine grained SILTSTONE/MUDSTONE interbedded with units of fine grained SANDSTONE up to 80mm.*

Weathering: *Locally slightly weathered to moderately weathered, occasionally highly weathered, recovery as grey sandy clay and silt, otherwise weathered with brown orange surface staining, occasionally penetrating up to 2-3mm.*

Fractures*: Discontinuity Set 1: sub-horizontal to 15 degrees, close to medium spaced, rough, undulating, occasional planar, moderately tight to open, generally with clay and silt smeared on surfaces.*

Discontinuity Set 2: 40-60 degrees, closely spaced, moderately open, rough, undulating, silt smeared.

Discontinuity Set 3: 75-85 degrees, moderately tight to very tight, rough to occasionally smooth, planar to stepped, typically silt smeared.

27.85-39.1m

Lithology: *Weak becoming medium strong grey thinly bedded fine to medium grained SANDSTONE interbedded with siltstone and mudstone.*

Weathering: *Fresh locally slightly to moderately weathered adjacent to discontinuity surfaces with some brown orange surface staining.*

Fractures*: Discontinuity Set 1: sub-horizontal to 20 degrees, close to medium spaced, rough planar to undulating, moderately open to moderately tight and generally clean.*

Discontinuity Set 2: 45-70 degrees, close to medium spaced, rough, undulating to occasionally stepped, moderately tight and generally clean.

39.1-50.55m

Lithology: *Very weak to weak grey mottled light and dark grey thinly laminated fine grained MUDSTONE/SILTSTONE occasionally interbedded lenses of sandstone (TURBIDIC).*

Weathering: *Locally highly weathered adjacent to discontinuity surfaces with frequent recovery of fine to coarse sand, angular gravel fragments and silt and clay.*

Fractures*: Discontinuity Set 1: typically 5-15 degrees, rough undulating, close to medium spaced and clay-silt infilled. No discernable bedding-core extremely weak in multiple orientations slightly stronger below 44.80m recovery generally more intact.*

Conclusions BH04-EC

The core shows extensive presence of thin coarser laminations that define bedding planes. Typically, much of the section is heterolithic linsen bedding with local wavy and flaser bedding.

The remainder of the borehole record and the examined core are consistent with this being part of the Kinsale Formation Cuskinny Member.

Bedding dip (Fig 5.1)
Box 1-80-90º
Box 2-60-70º
Box 3-80º
Cleavage appears to be close to the bedding.

BH05-EC
17.25-18.6m

Lithology: *Weak to occasionally medium strong grey thinly laminated to thinly bedded fine-grained SILTSTONE/MUDSTONE with occasional bands of interbedded fine grained sandstone.*

Weathering: *Fresh, locally slightly weathered adjacent to discontinuity surfaces with typical brown orange surface staining, occasionally penetrative up to 1-2mm.*

Fractures*: Discontinuity Set 1: 20-35 degrees, closely spaced, rough, undulating to occasionally stepped, moderately tight and generally clean occasionally with silt smearing on surfaces.*

Discontinuity Set 2: 75 degrees to sub-vertical, smooth occasionally rough, planar to stepped, moderately tight and clean with occasional silt smearing.

18.6-47.7m

Lithology: *Very weak becoming medium strong (extremely weak along bedding planes) with depth, light grey to dark grey (occasionally very) thinly laminated to thinly bedded fine grained MUDSTONE interbedded with thin lenses of fine to medium grained flaser bedded sandstone.*

Weathering: *Fresh, locally slightly to occasionally moderately weathered adjacent to bedding planes and discontinuity surfaces with brown orange surface staining frequently occurring in upper 10m of strata, occasionally penetrating 1-2mm.*

Fractures*: Discontinuity Set 1: sub-horizontal to 40 degrees, rough, stepped, crenulated to undulating, very close to closely spaced, moderately open to occasionally tight and brown orange stained.*

Discontinuity Set 2: 75 degrees to sub-vertical, rough undulating to stepped, moderately tight, closely spaced with occasional brown orange staining and occasional silt/clay smearing (fractures often clean and extremely tight, made prominent by drilling process).

47.7-50.5m

Lithology: *Weak to medium strong grey thinly bedded fine to medium grained SANDSTONE interbeded with siltstone.*

Weathering: *Fresh, locally slightly weathered along siltstone bedding planes with silt infill up to 2-3mm.*

Fractures*: Discontinuity Set 1: sub-horizontal to 15 degrees, rough planar to undulating, close to medium spaced, tight and generally silt/clay smeared.*

Discontinuity Set 2: 40-65 degrees, rough, planar to undulating, close to medium spaced, moderately tight and clean.

Conclusions

The borehole record is consistent with this being part of the Kinsale Formation Cuskinny Member, probably the upper part of the member.

The core shows extensive presence of thin coarser laminations that define bedding planes. Typically, much of the section is composed of heterolithic linsen bedding.

Bedding dip
27-34m about 70°
37-40m about 50-60°
40-55m dip decreases to about 20°

BH06-EC
10-38m
Lithology: *Very weak to occasionally medium strong grey to light grey thinly laminated to thinly bedded fine-grained MUDSTONE.*

Weathering: *Fresh, locally slightly weathered adjacent to discontinuity surfaces with some surface discolouration to dark grey and black and occasional silt and clay infill on surfaces and banding up to 15mm thickness (Highly to completely weathered from 10.00m - 11.50m).*

Fractures*: Discontinuity Set 1: 35-60 degrees, rough to smooth planar to undulating, occasionally stepped, very close to closely spaced, very tight to occasionally moderately open and typically with brown or staining and occasional silt smearing.*

Discontinuity Set 2: 75 degrees to sub-vertical, rough stepped to undulating, tight and generally clean, occasionally with silt smearing (quality of rock generally increasing with depth and strength increases also).

38-50.6m
Lithology: *Medium strong to strong grey thinly bedded fine-grained MUDSTONE interbedded with siltstone/mudstone.*

Weathering: *Fresh, locally slightly weathered adjacent to discontinuity surfaces with some surface discoloration to dark grey and black and occasional silt and clay infill on surfaces and banding up to 15mm thickness.*

Fractures*: Discontinuity Set 1: 35-60 degrees, rough to smooth planar to undulating, occasionally stepped, very close to closely spaced, very tight to occasionally moderately open and typically with brown or staining and occasional silt smearing.*

Discontinuity Set 2: 75 degrees to sub-vertical, rough stepped to undulating, tight and generally clean, occasionally with silt smearing (quality of rock generally increasing with depth and strength increases also).

Conclusions BH06-EC
From 10m to 38.5m, the borehole lithological record and core material are consistent with this being part of the Kinsale Formation Cuskinny Member, probably the upper part of the member.

The core shows extensive presence of thin coarser laminations and burrowing levels that define bedding planes. Typically, much of the section is heterolithic linsen bedding with a high proportion of mudstone/siltstone.

A localized 20cm weakly calcareous level was observed at 39.5m in mudstones/siltstones. This appears to be due to invading carbonate-rich hydrothermal fluids possibly migrated along cleavage planes or joints. This is probably a late diagenetic feature.

A 25cm long joint with two intersecting joints at about 49.5m contain a thin (< c.1mm) crystalline carbonate mineral. This is clearly a late stage precipitate from carbonate-rich hydrothermal fluids which migrated through the joints during the un-roofing stage of the orogen. The higher occurrence of carbonate at 39.5m may well be linked to this vein system. These carbonate occurrences in no way suggest that the bedrock lithologies are limestones.

The 12.6m section is predominantly (c.98%) composed of siliciclastic non-carbonate (non-limestone) heterolithic flaser and linsen bedded rock. The whole section is clearly part of the Cuskinny Member, which is a non-carbonate member.

Bedding dip
27m about 70°
31m about 80°
38.7- 50.6m about 80°

Cleavage
Appears to be closely parallel to the bedding.

BH07-EC
12.6-13.5m
Lithology: *Possible SILTSTONE BEDROCK.*

13.5-15.1m
Lithology: *Completely weathered SILTSTONE/SANDSTONE recovered as silty sandy angular to subangular gravel.*

15.1-41m
Lithology: *Weak (along bedding planes) to occasionally medium strong grey to dark grey occasionally dark red thinly bedded fine to medium grained SANDSTONE and thinly laminated fine-grained SILTSTONE.*

Weathering: *Fresh, locally slightly to moderately weathered adjacent to discontinuity surfaces with some brown orange surface staining and occasional silt smearing.*

Fractures*: Discontinuity Set 1: 10-30 degrees, rough, planar to occasionally undulating and stepped, closely spaced, moderately tight and generally discoloured red orange with occasional silt smearing.*

Discontinuity Set 2: sub-vertical, rough planar, moderately open and generally clean, occasionally discoloured brown orange.

Discontinuity Set 3: present (below 20.00m), 65-80 degrees, rough planar, occasionally smooth, closely spaced, moderately open to moderately tight and clean Occasional quartz and calcite veining up to 15mm thickness throughout.

41.00-50.35m
Lithology: *Medium strong to strong grey thinly laminated to thinly bedded fine to medium grained SANDSTONE interbedded with fine to medium grained mudstone and siltstone intraclasts.*

Weathering: *Fresh, locally slightly weathered adjacent to discontinuity surfaces to brown orange occasional penetrative stained up to 1-2mm.*

Fractures*: Discontinuity Set 1: 10-30 degrees, rough planar to stepped, occasionally undulating, closely spaced, moderately tight and discoloured grey brown.*

Discontinuity Set 2: 70 degrees, sub-vertical, planar rough to undulating, moderately tight to moderately open and generally silt smeared dark grey bands of brecciation throughout.

From 42.04m - 42.39m: quartz/calcite vein, 100mm thick, solution weathered clearly visible. From 43.90m - 45.02m: up to 15mm thickness.

Conclusion BH07-EC

It is difficult on the basis of the log and core photographs alone to assign this succession between 12.60m and 50.35m to a particular stratigraphical formation. However, the *Conodate* report provides important information (the presence of red beds), which together with the core and log suggest that this sequence is probably from the upper part of the Gyleen Formation Ballyknock Member. This is supported by the core examination.

Bedding dip
17.8m - 30°
28m - 25-30°
29.75m - 30°
38.75m - 40°
43.25m - about 20°
49.25-50m-about 20°- 30°
50.00-50.35m – about 45° Joints 80°

BH08-EC

16.70-26.50m

Lithology: *Extremely weak to weak (along bedding planes) becoming medium strong with depth, grey to dark grey very thinly laminated to thinly bedded fine grained MUDSTONE interbedded with flaser bedded sandstones.*

Weathering: *Locally fresh to slightly weathered adjacent to discontinuity surfaces with recovery occasionally as silt/clay with some fine grained sand, otherwise fresh.*

Fractures*: Discontinuity Set 1: sub-horizontal to 20 degrees, rough planar to undulating, occasionally stepped, close to occasionally medium spaced, moderately open to moderately tight, generally clean, occasionally with silt/clay smearing on surfaces.*

Discontinuity Set 2: 65-85 degrees, rough to smooth, planar occasionally stepped closely spaced, moderately tight and generally clean.

26.50-29.95m

Lithology: *Medium strong thinly bedded fine to medium grained SANDSTONE with SILTSTONE.*

30.00-43.65m

Lithology: *Extremely weak to weak (along bedding planes) becoming medium strong with depth, grey to dark grey very thinly laminated to thinly bedded fine grained MUDSTONE interbedded with siltstone and fine grained sandstone.*

Weathering: *Locally fresh to slightly weathered adjacent to discontinuity surfaces with recovery occasionally as silt/clay with some fine grained sand, otherwise fresh.*

Fractures*: Discontinuity Set 1: sub-horizontal to 20 degrees, rough planar to undulating, occasionally stepped, close to occasionally medium spaced, moderately open to moderately tight, generally clean, occasionally with silt/clay smearing on surfaces.*

Discontinuity Set 2: 65-85 degrees, rough to smooth, planar occasionally stepped, closely spaced, moderately tight and generally clean.

26.50m - 29.95m: *Medium strong thinly bedded fine to medium grained SANDSTONE with SILTSTONE*

Conclusions BH08-EC

At about 41-42m (Box 17), thin (<1mm) localised calcareous vein infillings along steep (65-70°) joints are present. These are the product of secondary injections of mineralised carbonate-rich hydrothermal fluids.

The general appearance of the rock is consistent with it being part of the Kinsale Formation (Cuskinny Member).

Bedding Dip is about 20-30° throughout most of the core with local increases up to 45-55° near the base.

The low bedding inclination might indicate the presence of a fold axis and/or faulting at this location which would be expected in view of its location close to a folded zone in the adjacent shoreline section.

Cleavage is about 62-90°.

BH09-EC

18.5-19.5m

Lithology: Possible WEATHERED ROCK.

19.50m-23.70m

Lithology: Highly weathered MUDSTONE recovered as sandy gravelly angular cobbles in a clay/silt matrix.

23.70-36.00m

Lithology: *Very weak to weak grey thinly laminated fine-grained MUDSTONE.*

Weathering: *Moderately weathered with recovery often as highly to completely weathered sandy gravel in silt/clay matrix.*

Fractures*: Discontinuity Set 1: 10-25 degrees, rough planar to undulating, closely spaced, moderately open and clay/silt filled up to 20mm.*

Discontinuity Set 2: 40-60 degrees, rough undulating to stepped, close to medium spaced, moderately open and typically clay/silt smeared.

36.00-46.90m

Lithology: *Weak becoming medium strong light to dark grey thinly bedded fine to medium grained SANDSTONE interbedded with siltstone/mudstone.*

Weathering: *Fresh, locally slightly weathered adjacent to discontinuity surfaces with occasional orange brown discolouration and penetrative staining up to 2-3mm, occasional silt/clay bands up to 5-6mm thickness.*

Fractures*: Discontinuity Set 1: 40-60 degrees, rough planar to stepped, close to medium spaced, open and generally silt/clay smeared.*

Discontinuity Set 2: sub-horizontal to 25 degrees, rough planar to undulating stepped, close to medium spaced, moderately open and typically discoloured orange brown with occasional quartz veining.

Conclusions BH09-EC

The sequence is mudstone dominant and strongly heterolithic with both flaser and linsen bedding. The core exhibits all the characteristics of either the Old Head or Kinsale Formation Cuskinny Mbr.

Bedding dip is shallow up to about 25°.

RC102-EC

8-11.9m

Lithology: *Weak, green MUDSTONE. Slightly weathered. Clay smearing. Pervasive brown oxide staining. Fractures: Closely spaced. Fractures dip approximately 20-30 degrees with undulating smooth surfaces.*

11.9-19m

Lithology: *MUDSTONE. Slightly weathered. Clay smearing. Pervasive brown oxide staining. Fractures: Closely spaced. Fractures dip approximately 20-30 degrees with undulating smooth surfaces.*

Conclusions RC102-EC

Bedding/lamination appears to be inclined at about 25-35°. Sandstones containing some quartz veins appear to be present in Boxes 3 and 4. Visual examination of this core is stratigraphically inconclusive. However, it is highly likely that the core is from the Cuskinny Member of the Kinsale Formation.

16.3-Petrography and mineralogical composition

Detailed petrographical analyses have been carried out by *Conodate Geology* on Boreholes BH04-EC to BH09-EC. This report is contained in *Causeway Geotechnical Report 13-381 Factual*. The *Conodate* report provides an important detailed analysis of the mineralogical composition of selected samples of the bedrock, the findings of which may have a significant bearing on the drilling procedures adopted. The report should be viewed in conjunction with this report.

An important component of the bedrock is the mineral Quartz. This accounts for 57-84% in sandstones and 20% in mudstones.

The results of the petrographical analysis, gives an indication of the mineralogical composition of the bedrock in the Cuskinny and Ballyknock Members. These are summarised below. The results from Boreholes BH05-EC to BH07-EC are particularly important.

The information is given as; Mineral/Volume % /Crystal or Grain size mm/ Origin

BH04-EC 30m
Sandstone
Quartz 68% 0.1-0.4mm Primary
Clay Mineral 20% <0.01mm Primary / Secondary
Mud 10% <0.01mm Primary
Muscovite <0.5% 0.2-0.4mm Primary
Pyrite <0.5% <0.1-0.3mm Primary
Ilmenite <0.5% <0.1mm Primary
Zircon <0.1% 0.3mm Primary

BH05-EC 22.4m
Heterolithic Sandstone dominant

Quartz 58% 0.1-0.3mm Primary
Clay Mineral 30% <0.01mm Primary / Secondary
Feldspar 7.0% 0.1-0.2mm Primary
Mud 3.0% <0.01mm Primary
Muscovite 1.0% 0.1-0.4mm Primary
Pyrite <0.5% <0.1mm Primary
Ilmenite <0.5% <0.2mm Primary
Zircon <0.1% <0.1mm Primary

BH05-EC 44.6m
Heterolithic Sandstone 60%, Mudstone 40%
Quartz 55% 0.1-0.3mm Primary
Clay Mineral 35% <0.01-0.3mm Primary / Secondary
Feldspar 3.0% 0.1-0.2mm Primary
Mud 3.0% <0.01mm Primary
Muscovite 2.0% 0.1-0.3mm Primary
Zircon 0.5% <0.1-0.3mm Primary
Pyrite 0.5% <0.1mm Primary
Ilmenite <0.5% 0.2mm Primary

BH06-EC 28m
Mudstone/siltstone/fine sandstone
Quartz 57% <0.1-0.2mm Primary
Clay Mineral 35% <0.01-0.2mm Primary / Secondary
Mud 5.0% <0.01mm Primary
Muscovite 2.0% 0.1-0.2mm Primary
Pyrite 1.0% <0.1-0.2mm Primary

BH07-EC 21m
Siltstone
Clay Mineral 45% <0.01mm Primary / Secondary
Quartz 30% <0.1mm Primary
Hæmatite 20% <0.01mm Primary / Secondary
Muscovite 4.0% 0.1mm Primary
Ilmenite <0.5% <0.1mm Primary
Pyrite <0.5% <0.1mm Primary

BH07-EC 43m
Sandstone with mudstone layers
Quartz 65% 0.1-0.3mm Primary
Clay Mineral 20% <0.01mm Primary / Secondary
Feldspar 10% 0.1-0.2mm Primary
Muscovite 3.0% 0.2-0.5mm Primary
Pyrite 2.0% <0.3mm Primary / Secondary

BH08-EC 25m
Mudstone
Clay Mineral 76% <0.01mm Primary
Quartz 20% <0.05mm Primary
Muscovite 3.0% <0.1mm Primary
Pyrite <0.1% <0.01mm Primary
Ilmenite <0.5% <0.1mm Primary
Hæmatite <0.1% <0.1mm Secondary

BH09-EC 43m
Sandstone
Quartz 84% 0.1-0.5mm Primary
Clay Mineral 10% <0.01-0.3mm Primary / Secondary
Feldspar 5.0% 0.2-0.4mm Primary
Muscovite <0.5% 0.1-0.6mm Primary

Ilmenite <0.5% <0.1mm Primary
Hæmatite <0.5% <0.2mm Primary / also weathered

The *Boregis* report made the following comment regarding the quartz content of the bedrock.

Quartz content of sedimentary rocks, especially sandstone, can be important when drilling due to the abrasiveness of the mineral. Typically quartz content in softer sandstone rocks should not be a concern for drill tool wear, however when rock quality is poor and the tools are required to undertake additional rotational work for additional pre-reaming and/or hole swabbing then monitoring of tool wear and employment of appropriate drilling mud management are important factors in ensuring success.

16.4-Weathering Patterns and Rock Strength

Weathering patterns of the bedrock have been described in the *Boregis* report as follows;

At deeper elevations, generally the quality of the rock generally improves although there are still portions of some boreholes with very poor rock quality.

Uniaxial Compressive Strengths (UCS) test results from fifteen EC2 samples taken from the better rock generally at between 40 and 50m depth saw values up to 53.13MPa and average strength of 28MPa suggesting the best rock strength is generally moderate to strong. The degree of discontinuities and the evidence from the rock cores indicates that a significant amount of lower strength rock is also present.

Point Load Index values Is(50) generally concur with the UCS testing when an appropriate conversion factor is employed. One high Is(50) was recorded suggesting that occasionally very strong rocks might be encountered.

17-CORE IN OFFSHORE ESTUARY EC2 BOREHOLES

Examination of the core from the offshore EC2 boreholes was carried out by the author on the 16th to the 23rd May 2016. The resulting logged information is summarised in Figs 14.1-14.11. The *Priority Geotechnical* logs are summarised below.

17.1-Summary Description of core from Boreholes RC01-EC2 to RC07-EC2

The following summarises information from *Priority Geotechnical* borehole logs (dated June 2016). These logs should be viewed in conjunction with this report.

Information on lithologies, weathering and fractures/discontinuities in italics below is derived from the *Priority Geotechnical* borehole logs (dated June 2016).

RC01-EC2

-15.15-21.15m

Lithology: *Moderately weak to moderately strong, red, thinly bedded fine-grained SANDSTONE.*

Weathering: *Moderately to highly weathered with frequent orange brown oxidation colouration on fracture surfaces discontinuities.*

Fractures: *2 apparent sets. Set 1 is dipping 75-90 degrees with planar to undulating smooth fracture surfaces and close.*

-21.15-31.8m

Lithology: *Strong, red, thin to thickly bedded, fine to medium grained SANDSTONE with inter-beds of brown green fine to medium grained Sandstone.*

Weathering: *Slightly to highly weathered with brown orange oxidation colouration along fracture edges and occasional discontinuities throughout unit.*

Fractures: *2 sets. Set 1 is dipping 5-20 degrees with planar to undulating smooth fracture surfaces and close to medium spacing. Set 2 is dipping 60-80 degrees with planar to undulating rough fracture surfaces and very close to medium fracture spacing.*

-31.8-40.9m

Lithology: *Weak to moderately weak, medium bedded red SILTSTONE with fine grained Sandstone beds.*

Weathering: *Moderate to highly weathered with frequent discontinuities, loss of strength and orange brown oxidation colouration on fracture surfaces.*

Fractures: *3 apparent sets. Set 1 is dipping 45-60 degrees with planar to undulating rough fracture surfaces and close to medium spacing. Set 2 is dipping 5-20 degrees with planar to undulating smooth fracture surfaces and very close to medium fracture spacing. Set 3 is dipping 80-90 degrees with undulating rough to smooth fracture surfaces and very close to medium spacing.*

-40.9-49.95m

Lithology: *Moderately weak to strong, grey brown SANDSTONE with occasional quartz veining parallel to bedding.*

Weathering: *Slightly to moderately weathered with orange brown oxidation colouration along fracture surfaces and occasional discontinuities.*

Fractures: *2 apparent sets. Set 1 is dipping 15-20 degrees with planar to undulating smooth fracture surfaces and close to medium fracture spacing. Set 2 is dipping 70-80 degrees with planar smooth to rough fracture surfaces*

RC02-EC2

-16.82-50.52m

Lithology: *Strong, medium to thickly bedded, grey green, fine grained SANDSTONE with Siltstone inter-beds, quartz veining.*

Weathering: *Slight to moderately weathered with orange purple oxidation colouration along fracture surfaces, local discontinuities and clay minor clay infill.*

Fractures: *3 apparent sets. Set 1 is dipping 45-70 degrees with undulating smooth to rough fracture surfaces and close to medium spacing. Set 2 is dipping 10-35 degrees with undulating to steppedsmooth to rough fracture surfaces and very close to medium fracture spacing. Set 3 is dipping 85-90 degrees with planar to undulating smooth to rough fracture surfaces and medium to wide spacing.*

RC03-EC2

-26.7-60.0m

Lithology: *Moderately weak, blue grey, medium bedded, fine grained SANDSTONE with Siltstone interbeds and quartz mineralization in part.*

Weathering: *Moderately weathered with sections ranging from slightly to highly weathered. Minor brown orange oxidation colouration on fracture surfaces, clay infill along fractures and observable discontinuities.*

Fractures: *3 apparent sets. Set 1 is dipping 40-65 degrees with planar to undulating smooth fracture surfaces and close to medium spacing. Set 2 is dipping 85-90 degrees with undulating rough fracture surfaces and medium to wide spacing. Set 3 is dipping 10-20 degrees with undulating smooth fracture surfaces and medium spacing.*

RC04-EC2
-30.7-44.2m
Lithology: *Weak to very weak, thin to thickly bedded, blue grey SHALE with Siltstone and Mudstone bands throughout unit.*

Weathering: *Highly weathered with heavy fracture and loss of strength. Common discontinuities throughout.*

Fractures: *3 sets apparent. Set 1 is dipping 45-70 degrees with planar to undulating smooth fracture surfaces and very close to medium spacing. Set 2 is dipping 80-90 degrees with planar smooth fracture surfaces and medium spacing. Set 3 is dipping 0-10 degrees with undulating rough fracture surfaces and medium to wide spacing.*

-44.2-56.15m
Lithology: *Medium bedded, light blue grey SILTSTONE with inter beds of fine grained grey blue Sandstone throughout unit. Shale bed at top of unit.*

Weathering: *Highly to locally moderately weathered with loss of strength, discontinuities and clay infill.*

Fractures: *4 sets apparent. Set 1 is dipping 5-20 degrees with planar to stepped smooth to rough fracture surfaces and close to medium spacing. Set 2 is dipping circa 45 degrees with planar to undulating smooth fracture surfaces and close to medium spacing. Set 3 is dipping 65-85 degrees with planar to stepped smooth fracture surfaces and very close spacing. Set 4 is dipping 90 degrees with planar to stepped smooth fracture spacing and medium to wide spacing.*

-56.15-60.15m
Lithology: *Moderately weak to locally very weak, light blue medium bedded SILTSTONE with weak to moderately weak medium bedded blue grey fine grained Sandstone at the bottom of unit. Mineralization infill in select fractures.*

Weathering: *Highly to moderately weathered locally with loss of strength and discontinuous throughout.*

Fractures: *2 sets apparent. Set 1 is dipping 45-60 degrees with planar to stepped smooth fracture surfaces and very close to close spacing. Set 2 is dipping 70-90 degrees with planar smooth to rough fracture surfaces*

RC05-EC2
-28.8-53.45m
Lithology: *Moderately strong, dark grey SILTSTONE with interbeds of thinly laminated Mudstone.*

Weathering*: Slightly weathered with brown oxidation colouration, minor loss of strength and clay smearing on fracture surfaces.*

Fractures: *3 sets apparent. Set 1 is dipping 30-40 degrees with planar smooth fracture surfaces and close spacing. Set 2 is dipping 60-70 degrees with undulating smooth fracture surfaces and close spacing. Set 3 is dipping 90 degrees with undulating smooth to rough fracture surfaces and wide spacing.*

-53.45-60.55m
Lithology: *Moderately strong to strong, dark grey blue SILTSTONE with interbeds of thinly laminated Mudstone.*

Weathering: *Slightly to locally moderately weathered with discontinuities in part.*

Fractures: *1 set dipping 40-60 degrees with planar to undulating smooth to rough fracture* *surfaces and close to medium fracture spacing.*

RC06-EC2

-19.35-21.25m

(WEATHERED ROCK)

Lithology: *Weak to moderately strong, green grey, medium bedded fine grained SANDSTONE with minor thin to medium bedded blue Siltstone bands.*

Weathering: *Highly weathered with orange brown staining on fracture surfaces and highly discontinuous.*

Fractures: *2 apparent sets. Set 1 is dipping 40-60 degrees with planar to undulating smooth fracture surfaces and close to medium spacing.*

-21.25-26.95m

Lithology: *Lithology: Weak to moderately strong, green grey, medium bedded fine grained SANDSTONE with minor thin to medium bedded blue Siltstone bands.*

Weathering: *Slightly to moderately weathered with oxidation colouration along fracture surfaces and occasional discontinuities.*

Fractures: *2 apparent sets. Set 1 is dipping 40-60 degrees with planar to undulating smooth fracture surfaces and close to medium spacing.*

-26.95-60.0m

Lithology: *Moderately strong to strong, grey blue, inter-bedded SANDSTONE and Siltstone.*

Weathering: *Slightly weathered with minor oxidation colouration on fracture surfaces and rare discontinuities.*

Fractures: *4 apparent sets. Set 1 is dipping 40-55 degrees with planar to undulating smooth fracture surfaces and close to medium spacing. Set 2 is dipping 85-90 degrees with planar to undulating smooth fracture surfaces and medium to wide spacing. Set 3 is dipping circa 75 degrees with planar smooth fracture surfaces and medium to wide spacing. Set 4 is dipping circa 10 degrees with stepped rough fracture surfaces and wide spacing.*

RC07-EC2

-18.4-20.5m

Lithology: *Moderately weak, green, fine grained SANDSTONE.*

-20.5-55.0m

Lithology: *Moderately strong to strong, thin to medium bedded, blue grey fine grained SANDSTONE with thin to very thin interlaminations of Siltstone, Shale and Mudstone throughout. Minor quartz veining throughout unit.*

Weathering: *Slightly to moderately weathered with orange brown oxidation colouration on fracture surfaces, penetrative in part to circa 1cm. Minor loss of strength along select units with clay infill on select fractures.*

Fractures: *2 apparent sets. Set 1 is dipping 20- 30 degrees with planar to undulating smooth fracture surfaces and close spacing. Set 2 is dipping 70-90 degrees with planar to undulating smooth fracture surfaces and medium to wide spacing.*

18-ROCKHEAD DEPTH AND THICKNESS OF SUPERFICIAL DEPOSITS

Information on the depth to rockhead and the thickness of the superficial deposits is contained in the borehole records that are summarized in Figs 11.1, 12.1, 12.2, 15.1, 15.2, 16.3 & 17.4.

The rockhead extends to a depth of at least -36.7mOD in BH04-EC2 (Fig 11.1). It should be noted that this may not be the greatest depth of the rockhead in this incised drowned estuary. Southward draining valleys in this region have been incised deeply during Inter-glacial and Post-glacial low stands in sea level.

A geophysical investigation, of part of the estuary crossing and adjacent areas was carried out by *APEX Geoservices*. Their report provides information on the seabed, the superficial deposits thickness and the rockhead (Figs 16.1-16.3). An extract from their report is shown here in italics.

The seabed elevation (Apex Drawing 13071/01 Figure 1) is between c. - 6m and -16m mOD.

The thickness of the superficial deposits ranges from c.2m to 13m over the surveyed area. This layer is thickest in parts of the east of the site, near Rushbrook and White Point (Apex Drawing 13071/03 Figure 3).

The bedrock elevation is between c. -10m and -22mOD in the area of the crossing according to the geophysical survey. The bedrock elevation is generally > - 18m mOD in the northern part of the area.

The above rockhead depths determined by geophysical methods need to be revised in the light of the EC2 borehole information.

19-REVIEW OF SUPERFICIAL DEPOSITS IN OFFSHORE EC BOREHOLE RECORDS

The following offshore boreholes are reviewed here; BH04-EC, BH05-EC, BH06-EC, BH07-EC, BH08-EC, BH09-EC (See Fig 13.1 for location and *Causeway Geotech* Report 13-381). The *Causeway Geotech* borehole logs should be viewed in conjunction with this report.

Causeway Geotech June 2015
Cork Lower Harbour Main Drainage Scheme-Ground Investigation Factual Report. Report 13-381 (BH01-EC to BH09-EC).

Causeway Geotech June 2015
Cork Lower Harbour Main Drainage Scheme-Ground Investigation Interpretive Report. Report 13-381a (BH01-EC to BH09-EC).

Information on the composition of these deposits is summarised in Figs 7.16, 15.1, 15.2 & 16.2).

In general, the superficial deposits are dominated by silts and clays. Gravels and sands appear to form a basal layer across the area. These pass upwards into a silt-dominated succession. However, gravels and sands in BH07-EC are separated by a thick clay unit.

It is clear that there are significant lateral gradations between the various sediment types in the offshore area as well as in the onshore Cork Dockyard area. Consequently, it would be difficult to speculate on possible correlations between the EC boreholes or on the three dimensional architecture of the deposits in the offshore EC boreholes in the absence of further information.

20-REVIEW OF SUPERFICIAL DEPOSITS IN OFFSHORE EC2 BOREHOLE RECORDS

The offshore boreholes adjacent to the estuary crossing are Boreholes BH01-EC2 to BH07-EC2 and RC01-EC2 to RC07-EC2.

Information on the thickness and composition of the superficial deposits in Boreholes BH01-EC2 to BH06-EC2, RC04-EC2 and RC07-EC2 was obtained from the *Priority Geotechnical* borehole records dated 9th to 20th June 2016. These records are summarised below. Their composition and distribution are illustrated in Fig 17.4.

The deposits infill a deep rock-floored channel which coincides with the north-south Passage West estuary. The deepest part of the channel is in the area of Borehole RC04-EC2 where the rockhead appears to lie at -36.7mOD. In general, the deposits appear to thicken towards the central part of the navigation channel.

A lower gravel unit is present between Boreholes BH03-EC2-RC07-EC2. This is overlain by, and grades laterally westwards into a thick silt dominated unit. Clays and sands are also locally present. The upper part of the superficial deposits contains a thin gravel level in four boreholes.

Silts consist of; Gravelly Silt, Sandy gravelly Silt, Gravelly sandy Silt.

Gravels contain; Gravel, Sandy Gravel, Silty Gravel, Sandy silty Gravel.

Clays consist of Clay and Silty sandy Clay.

The following summary descriptions are taken from *Priority Geotechnical* borehole records dated 9th to 20th June 2016.

BH01-EC2

-3.44 m to -4.44mOD

Very silty GRAVEL. Gravel is fine to coarse, sub-angular to sub-rounded.

-4.44m to -6.44mOD

Loose, grey, very soft very gravelly SILT.

-6.44m to -15.14mOD

Soft, grey, slightly sandy slightly gravelly SILT. Sand is fine to coarse. Gravel is fine to coarse, sub-angular.

-15.14m to -15.54mOD

(Weathered Rock) Recovered as: Dense GRAVEL with high cobble content. Gravel is angular, medium to coarse. Cobbles are angular, 63-120mm dia. Siltstone lithology.

BH02-EC2

-6.14m to -7.14mOD

Slightly silty GRAVEL with shell fragments. Gravel is fine to coarse, sub-angular.

-7.14m 70 to -9.14mOD

Very loose, grey, slightly gravelly sandy SILT. Gravel is fine to medium, sub-angular. Sand is fine to coarse.

-9.14m to -17.14mOD
Very soft becoming soft, grey SILT.

-17.14m to -18.09mOD
Firm, very gravelly SILT with wood fragments. Gravel is fine to coarse, angular.

The 'wood' fragments here are probably transported material that was derived from the higher ground at the margins of the channel by fluvial and/or mass transport mechanisms. It is likely that the material was deposited in early post Glacial times.

BH03-EC2
-15.25m to -16.25mOD
Grey, slightly gravelly slightly sandy SILT. Gravel is fine, angular to sub-angular. Sand is fine to coarse.

-16.25m to -18.25mOD
Soft, grey CLAY.

-18.25m to -19.45mOD
Loose becoming medium dense, grey, slightly sandy very silty GRAVEL with low cobble content. Sand is fine to coarse. Gravel is fine to coarse, angular to sub-angular. Cobbles are angular to sub-rounded.

-19.45m to -19.75mOD
Grey brown, SAND.

-19.75m to - 23.25mOD
Medium dense becoming dense, slightly silty sandy GRAVEL with low cobble content and low boulder content. Sand is fine to coarse. Gravel is fine to coarse, angular to rounded. Cobbles are angular to sub-rounded, 63-200mm dia. Boulders are angular to sub-angular.

-23.25m to -24.25mOD
Stiff, grey, sandy gravelly CLAY. Sand is fine to coarse. Gravel is fine to coarse, angular to sub-rounded.

BH04-EC2
-18m to -19mOD
Very silty GRAVEL. Gravel is fine to coarse, sub-angular.

-19m to -24.6mOD
Very soft to soft, dark grey, slightly sandy gravelly SILT. Sand is fine to coarse. Gravel is fine to coarse, sub-angular to sub-rounded.

-24.6m to -28.5mOD
Medium dense becoming dense, sandy GRAVEL with medium cobble content. Sand is fine to coarse. Gravel s fine to coarse, sub-rounded to rounded, Sandstone lithology. Cobbles are sub-rounded to rounded, Siltstone lithology.

-28.5m to -29.2mOD
Dense, brown grey, GRAVEL with high cobble content. Gravel is angular, Siltstone lithology. Cobbles are angular.

BH05-EC2
-21.5m to 22.5mOD
Slightly silty very sandy GRAVEL. Sand is fine to coarse. Gravel is fine to coarse, sub-angular to sub-rounded.

-22.5m to -23.5mOD

Very Soft, grey, very sandy SILT with shell content. Sand is fine to coarse.

-23.5m to -25.5mOD

Soft to firm, grey, slightly sandy gravelly SILT. Sand is fine to coarse. Gravel is fine to medium, sub-angular.

-25.5m to - 27.5mOD

Medium dense, purple grey, very sandy GRAVEL. Sand is fine to coarse. Gravel is fine to coarse, sub-angular to rounded.

-27.5m to -28.0mOD

Dense GRAVEL with high cobble content. Gravel is medium to coarse, Siltstone and Sandstone lithology. Cobbles are angular, 63-120mm dia. Siltstone and Sandstone lithology.

BH06-EC2

-17.7m to -18.46mOD

Very soft, dark grey, SILT with shell fragments.

-18.46m to -18.7mOD

Loose, slightly silty GRAVEL with low cobble content. Gravel is fine to coarse, angular to sub-rounded. Cobbles are angular to sub-rounded.

-18.7m to -19.55mOD

Slightly silty slightly gravelly COBBLES. Cobbles are angular to sub-angular, Sandstone and Siltstone lithology.

PART F-REFERENCES

21-GEOLOGICAL REFERENCES

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PART G-FIGURES

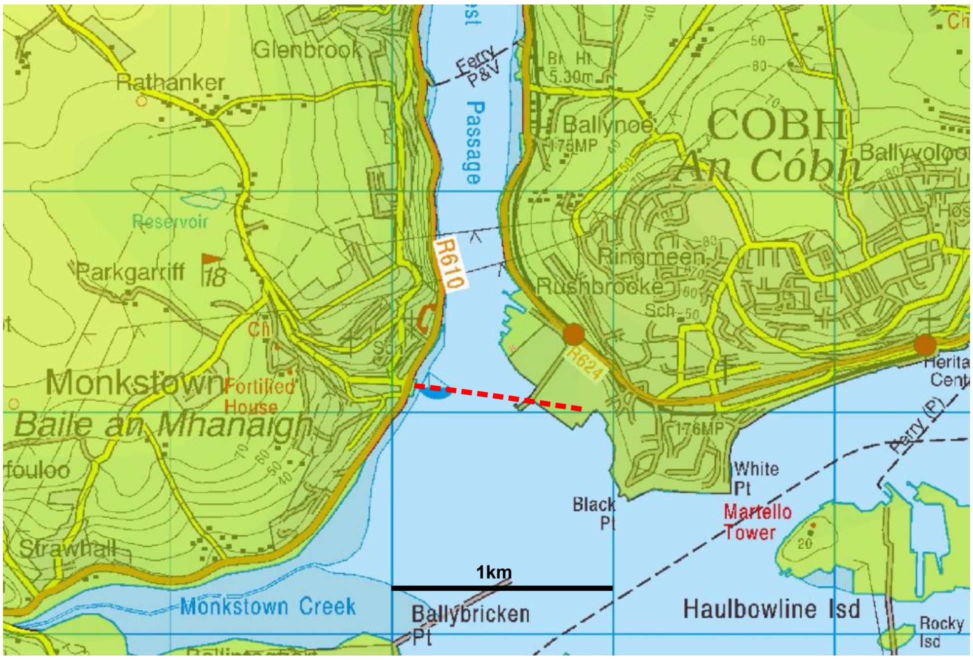


Fig 1.1. Ordnance Survey Ireland map showing the geographical setting of the Cobh-Monkstown estuary crossing route (dash red line).

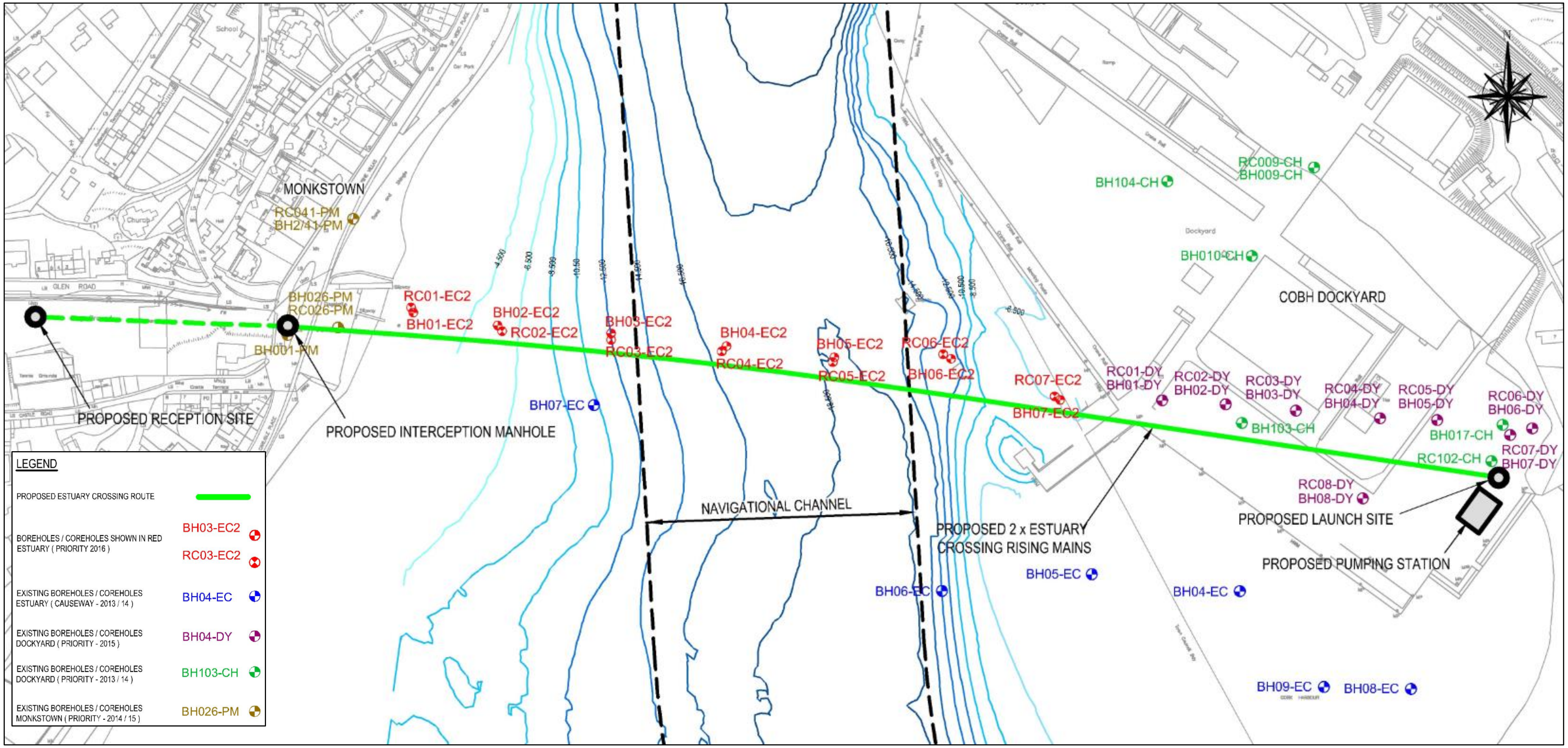


Fig 1.2. Map showing location of estuary crossing, topography of channel and location of boreholes.

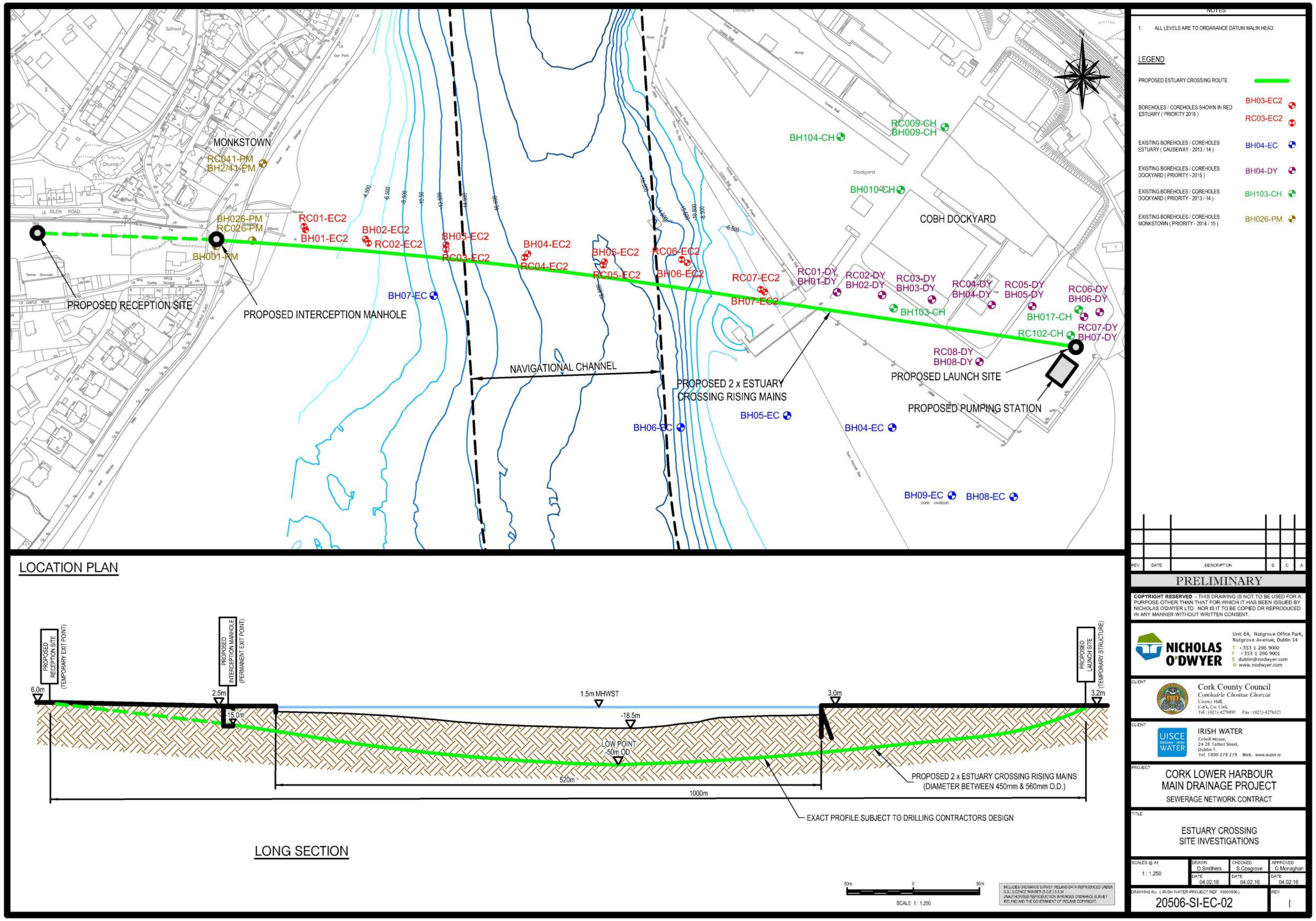


Fig 1.3. Drawing showing plan and section of the estuary crossing and borehole locations (Nicholas O'Dwyer Drawing No. DR 20506-SI-EC-02).

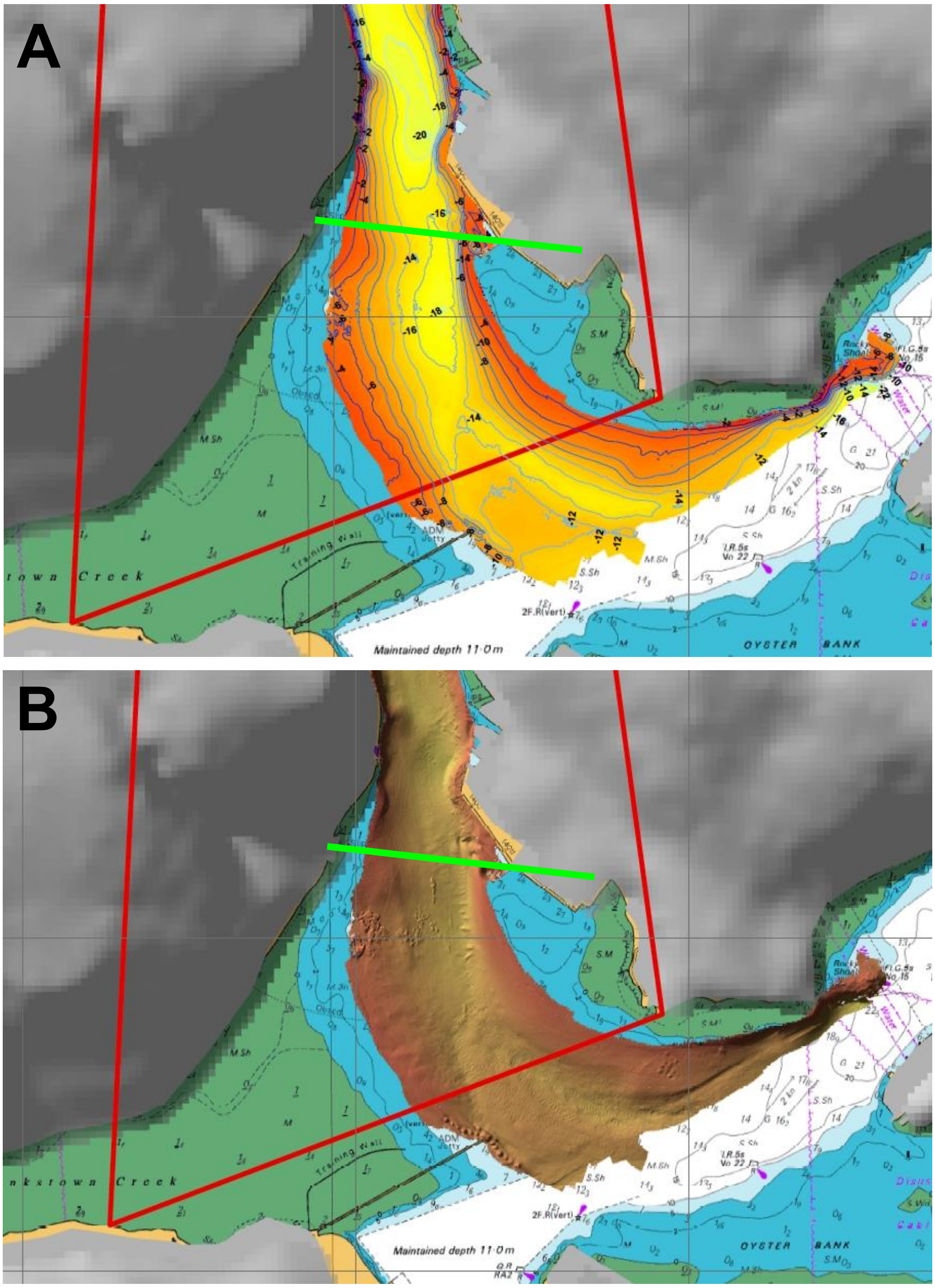


Fig 5.1. *Infomar* bathymetry (A) and shaded relief (B). Green line-Estuary crossing.

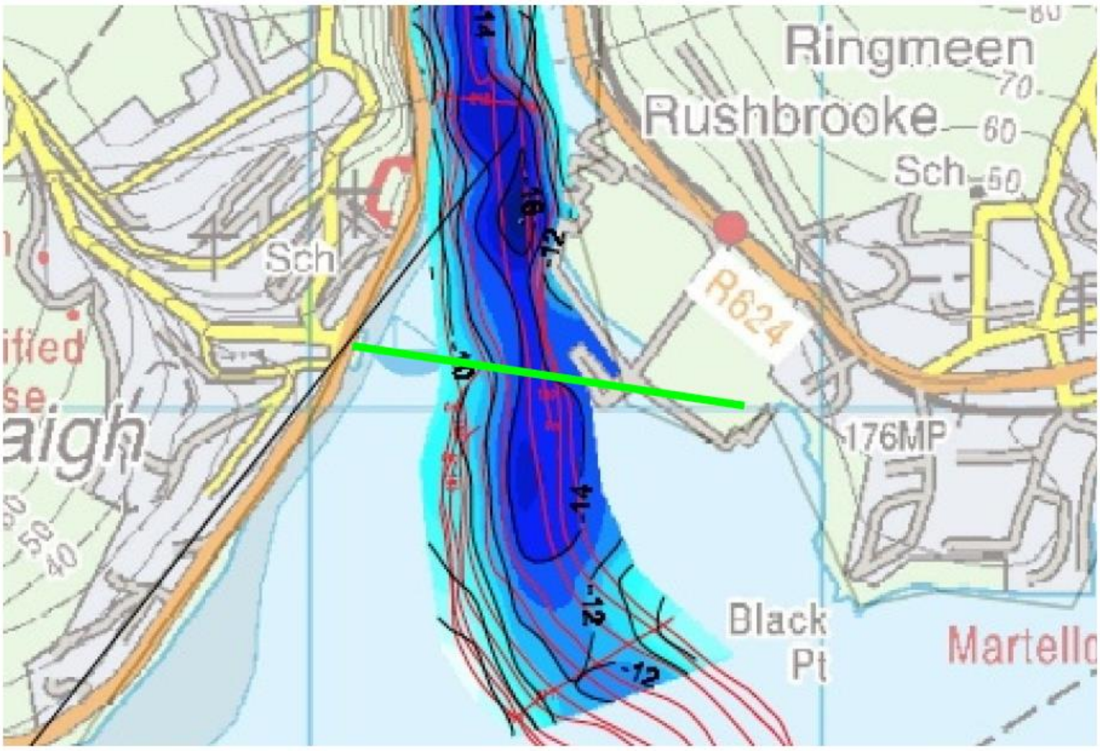


Fig 5.2. *Apex* Geoservices seabed elevation. Green line-Estuary crossing.

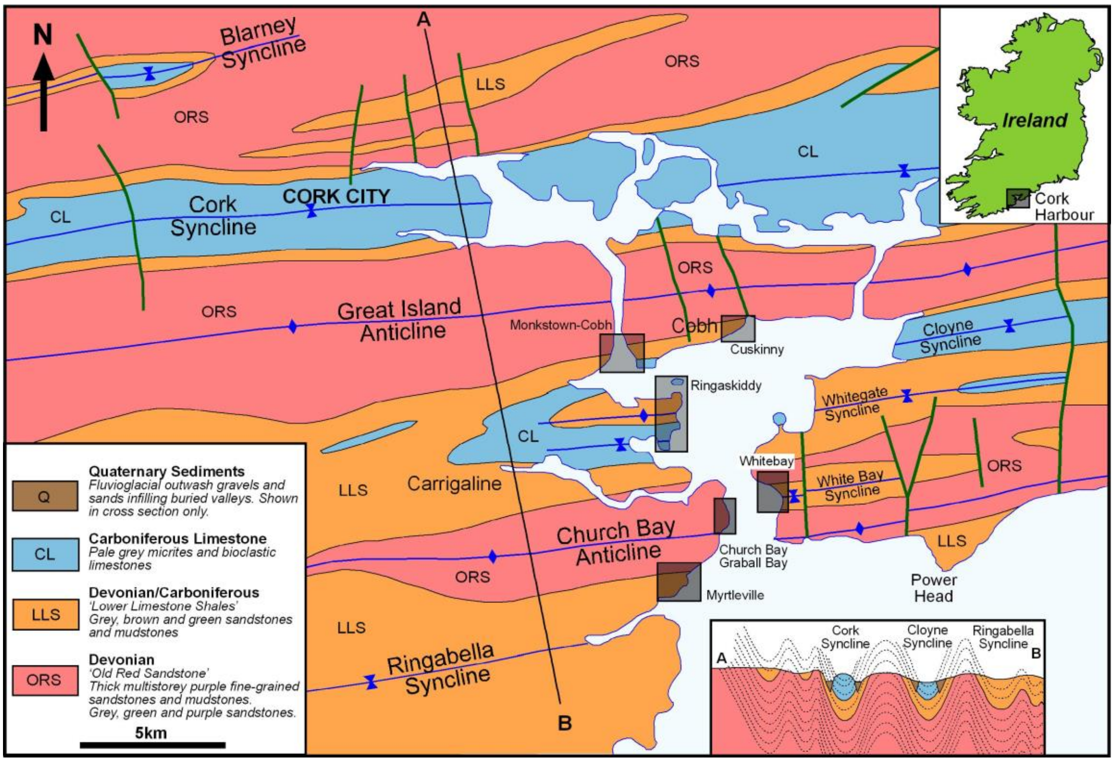


Fig 6.1. Cork Region Bedrock.

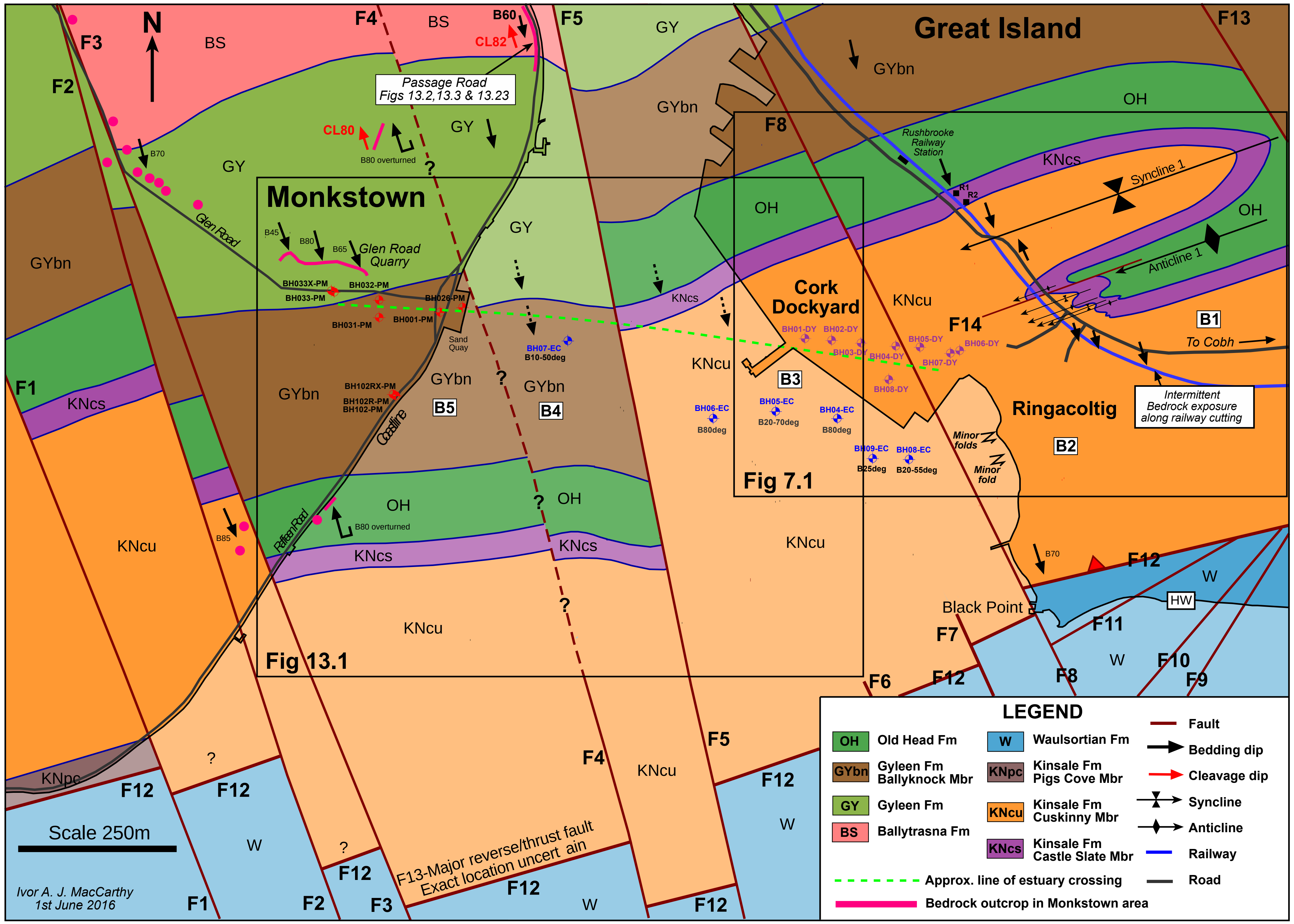


Fig 6.2. Model of bedrock geology in the Cobh-Monkstown crossing area. Boundaries shown are as predicted at the surface of the bedrock (rockhead). Formations shown in paler shades are offshore. The location and character of Fault F4, if present, is not certain B45deg etc.-Bedding dips observed in core. R1-R2-Locations of Palynology samples in railway section. See Figs 7.1 and 13.1 for detailed maps of outlined area. Detailed stratigraphical legend in Page 70. NOTE: There are three possible structural models for the Sand Quay area (See Section 14.5 and Figs 13.1a and 13.1b).

Stratigraphical Legend to Figs 6.2, 7.1, 7.2 and 13.1

W-Waulsortian Formation
This consists of pale grey crystalline limestones.

KNpc-Kinsale Formation Pig's Cove Member
This consists of grey siltstones.

KNcu-Kinsale Formation Cuskinny Member
This consists of alternating well-bedded grey sandstones, claystones, siltstones, and heterolithic (flaser, wavy and linsen bedded) sediments. Typically, the heterolithics show strong lithological separation between adjacent laminae. A number of mudstones/claystones are present one of which is about 12m thick at Cuskinny. Typically, the heterolithics show strong lithological contrast between adjacent laminae. The member is subdivided into four distinct units. These are:

KNcu1-Sandstone dominant with minor mudstones (Claystones/Siltstones)
KNcu2-A thin c.12-15m thick grey Mudstone (Claystones/Siltstones)
KNcu3-Sandstone dominant with minor mudstones (Claystones/Siltstones)
KNcu4-Mudstone dominant with minor sandstones and flaser-bedded levels.
Units 1, 3 and 4 contain extensive heterolithic levels.

KNcs-Kinsale Formation Castle Slate Member
This occurs as a thin (c.20-30m) unit of medium to dark grey mudstone (claystone and siltstone).

OH-Old Head Sandstone Formation
This is distinguished by the presence of well-bedded heterolithic rocks. These range from sandstone-dominated (flaser bedded heterolithics), equally proportioned sandstone and mudstone (wavy bedded heterolithics) to mudstone dominated (linsen bedded heterolithics) heterolithics. Typically, the formation is grey coloured where fresh and the sediments are thinly laminated throughout.

GYbn-Gyleen Formation Ballyknock Member
This is characterised by rapidly alternating green and grey, fine to medium-grained siltstones and sandstones.

GY-Gyleen Formation
This is characterised by regularly alternating fine to medium grained siltstones and sandstones. In general, the siltstones are of similar composition and appearance to those in the underlying Ballytrasna Formation. The sandstones are usually shades of green and grey. Sandstones occur in units up to c.10m in thickness while the mudstones and siltstones are generally red to purple and range up to about 20m in thickness.

BS-Ballytrasna Formation
The bulk of the formation is composed of red to purple mudstones and similarly coloured fine to medium grained siltstones and sandstones.

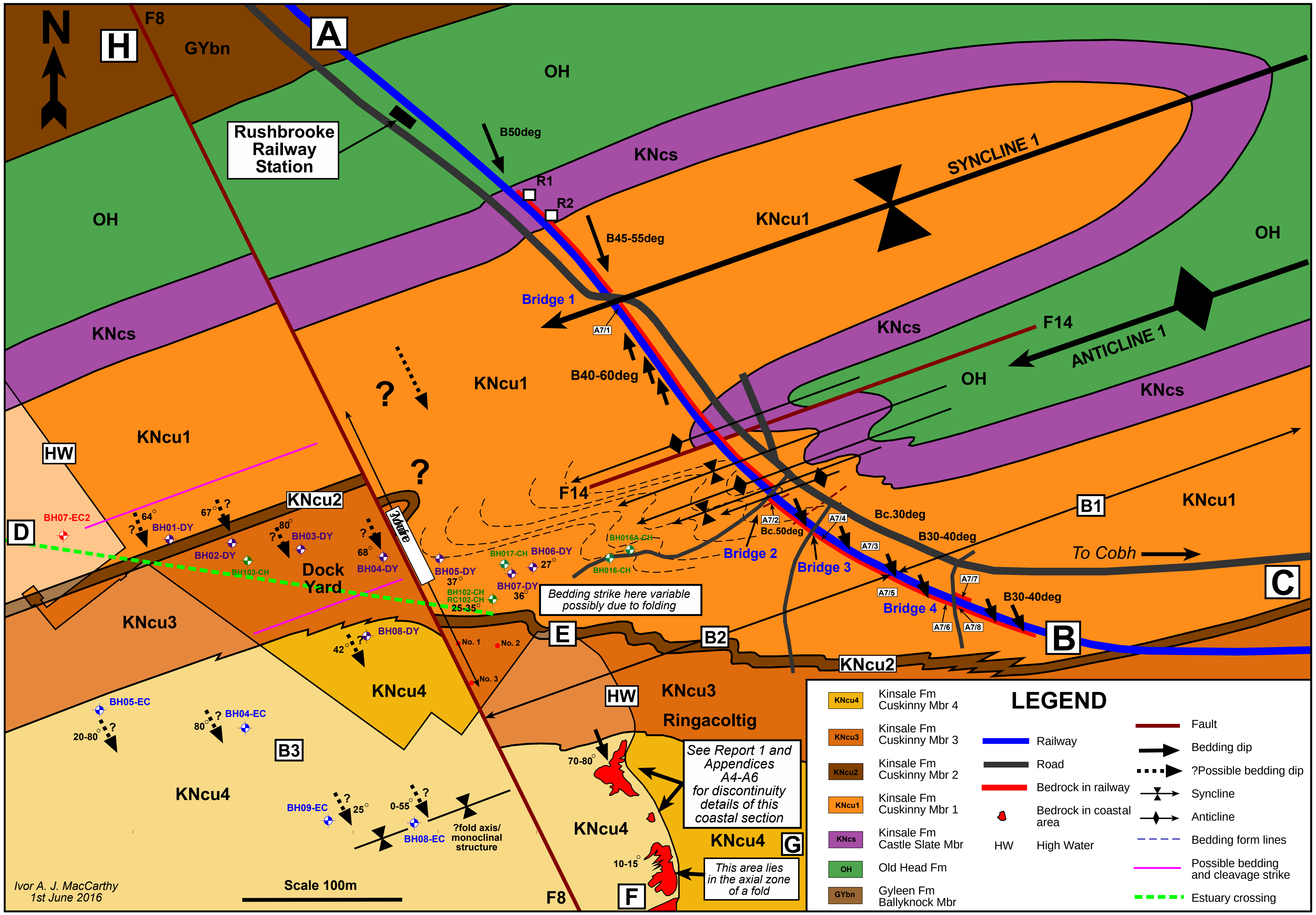


Fig 7.1. Detailed map of the bedrock geology of the onshore Cork Dockyard area. Formations in paler shade are located offshore. B45deg etc.-Bedding dips observed in core. The interpretations in Block 3 and the western part of Block 2 are highly speculative due to the absence of information on bedding dip directions in boreholes. Bedding form-lines are interpreted strike lines drawn on bedding planes. These indicate the structural form of the bedrock. Arrows on fold axes show plunge direction of the folds. R1 & R2-Palynology samples in railway section A7/1 etc. Location of photographs of railway section in Appendix A7. B1-B3- Structural blocks. The boundary between B1 and B2 is taken as the railway line. The boundary between B2 to B3 is Fault F8. A-H-Locations of lines of section shown in Fig 7.2. Detailed Stratigraphical legend located above. Stratigraphical boundaries away from bedrock outcrops are speculative. Detailed stratigraphical legend in Page 70..

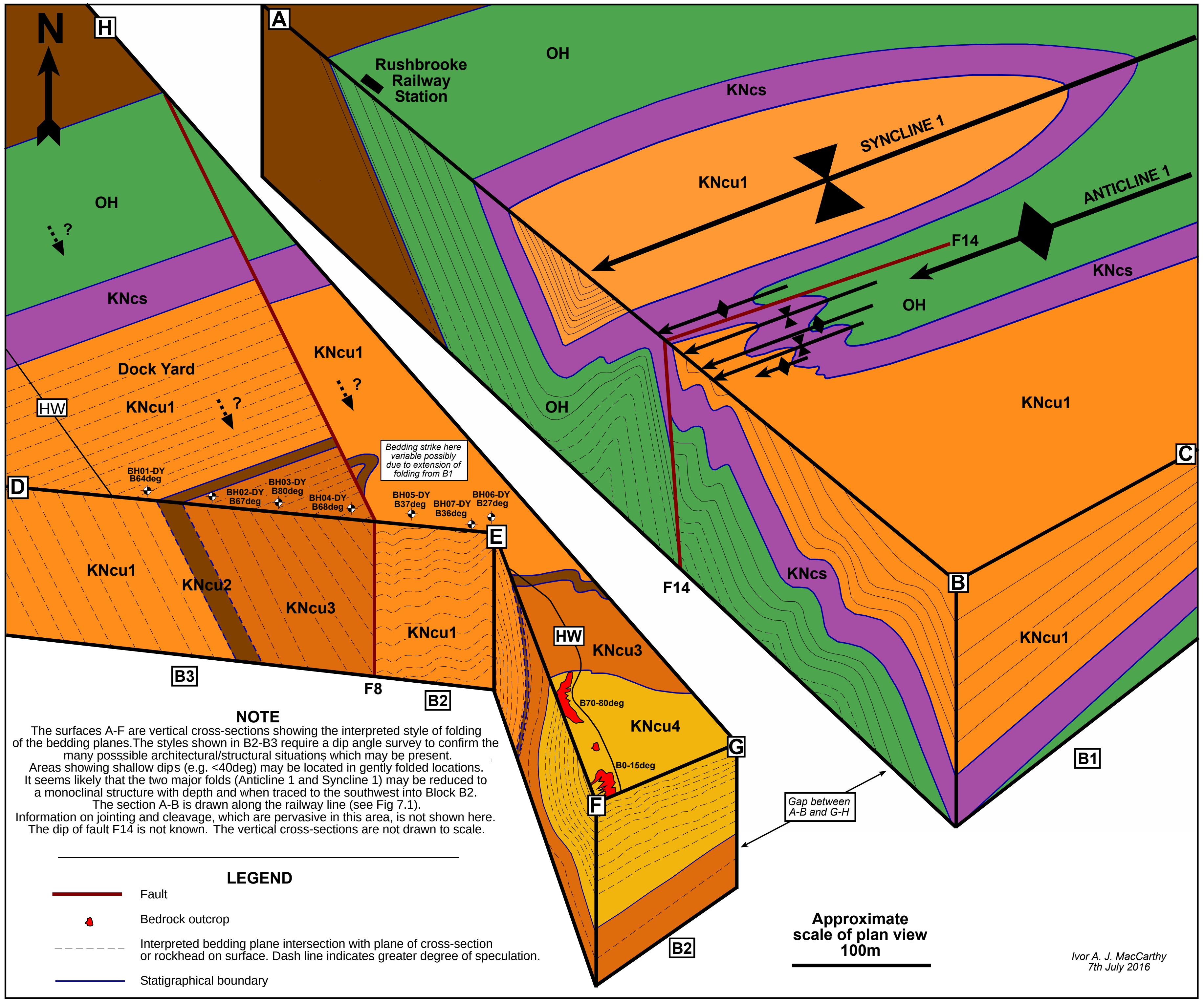


Fig 7.2. Block model of the Cork Dockyard area, Cobh showing the general structural style schematically. Section A-B corresponds to the railway line. See Fig 7.1 for location of sections. Detailed stratigraphical legend in Page 70.

	A	B	C	D	E	F	G	H	I	J	K
1	**RC01-DY**	**DEPTH**	**BOX THICKNESS**	**FINE/MED SANDSTONE**	**FLASER**	**SILTSTONE**	**CLAYSTONE**	**LINSEN**	**WEATHERED/BROKEN/GAPS**	**BEDDING DIP**	**NOTES**
2	**RC01-DY BOX 1**	16.5-25.2m	8.7m	175	20				675	70°	Weathering along joints 65°/W1-2/Sandstones N6/ ?GCF Quartz grains rounded
3	**RC01-DY BOX 2**	25.2-29.0m	3.8m	205					175	?90°	Qtz veins intersecting/10° & 60° sets /?Along joints
4	**RC01-DY BOX 3**	29-32.4m	3.4m	245					95	60°	Qtz veins /?faults
5	**RCO1-DY BOX 4**	32.4-35.3m	2.9m	250	25				15	70°	7 joints/40° & 60° sets intersecting
6	**RC01-DY BOX 5**	35.3-38.1m	2.8m	270					10	58°	Gy/G laminated Sandstone/ Joints 70° & 40°
7	**RC01-DY BOX 6**	38.1-40.8m	2.7m	230					40	65°	Gy/G laminated Med Sandstone/Qtz veins intersecting/?along joints/50° & 60° sets
8	**RC01-DY BOX 7**	40.8-43.6m	2.8m	230					50	50-60°	Joint sets 40°, 50° (10cm and 30cm spacing), Joint set 80-90°
9	**RC01-DY BOX 8**	43.6-46.6m	3m	100	90	60			50	50-65°	Palynology sample RC01-DY Box 8-42.0m Greyish Black (N2) Siltstone CONFIRMS LOWER CUSKINNY MEMBER (KNcu1)
10	**RCO1-DY BOX 9**	46.6-49.5m	2.9m	70	150	60			10	45-50°	Palynology sample RC01-DY Box 9-48.1m Med light Grey (N6) Siltstone CONFIRMS LOWER CUSKINNY MEMBER (KNcu1)
11	**RC01-DY BOX 10**	49.5-50m	0.5m			45			5		Palynology sample RC01-DY Box 10-49.7m Med light Grey (N6) Siltstone CONFIRMS LOWER CUSKINNY MEMBER (KNcu1)
12	**TOTALS cm**			1775	285	165			1125		**NOTE: Boxes 1-7 are distinguished by greenish grey fine to med laminated sandstones.**
13	**TOTALS %**			**52.99%**	**8.51%**	**4.93%**			**33.58%**	**Av 64°**	**Locally, these sandstones are interbedded with coarse levels.**
14											**Boxes 8-10 show very good lithological separation in heterolithic levels.**
15											**This, in conjunction with the character of the overlying sequence here (Boxes 1-7) and the palynology**
16											**analyses confirm that this borehole is in the Kinsale Formation Cuskinny Member (KNcu1).**
17											
18	**RC02-DY**	**DEPTH**	**BOX THICKNESS**	**FINE/MED SANDSTONE**	**FLASER**	**SILTSTONE**	**CLAYSTONE**	**LINSEN**	**WEATHERED/BROKEN/GAPS**	**BEDDING DIP**	**NOTES**
19	**RC02-DY BOX 1**	14.2-17.0m	2.8m	230					50	80°	Qtz veins/grey/green St with thin Slt streaks
20	**RC02-DY BOX 2**	17.0-20.0m	3m	215					85	85°+	
21	**RC02-DY BOX 3**	20.0-22.8m	2.8m	150					130	75°	Typical KNcu
22	**RCO2-DY BOX 4**	22.8-25.6	2.8m	210		30			40	70°	60cm Brown Weathered (W4) friable St/**GCF (Garryvoe *Conglomerate* Facies**)**Remainder W1/ KNcu
23	**RC02-DY BOX 5**	25.6-28.6m	3m	110					190	65°	Qtz veins at top
24	**RC02-DY BOX 6**	28.6-32.0m	3.4m	135			70	50	85	50°	1m Brown weathered friable St W4/**GCF (Garryvoe *Conglomerate* Facies)**/Joint 70°/W1/W4locally/Clay N2/*
25	**RC02-DY BOX 7**	32-34.9m	2.9m			230			60	55°	**Grey Mudstone Facies** /N4/Siltstones Fine Grained/Broken/W1
26	**RC02-DY BOX 8**	34.9-38.4m	3.5m			55	130		165	58°	**Grey Mudstone Facies** /N2/J70°/W1/Siltstones Very Fine Grained
27	**RC02-DY BOX 9**	38.4-41.4m	3m			160			140		**Grey Mudstone Facies**/Thin St streaks present
28	**RC02-DY BOX 10**	41.4-44.5m	3.1m			166		130	14		**Grey Mudstone Facies**/Joint 70°
29	**RC02-DY BOX 11**	44.5-47.7m	3.2m			100		60	160		**Grey Mudstone Facies**
30	**RC02-DY BOX 12**	47.7-50m	2.3m			210			20		Palynology sample RC02-DY Box 12-47.7m Med dark Grey (N4) Siltstone
31	**TOTALS cm**	3580		1050		951	200	240	1139		**NOTE: Boxes 1-6 are KNcu3. Boxes 7-12 Cuskinny Mbr (KNcu2 Mud Unit-Grey Mudstone Facies).**
32	**TOTALS %**			**29.33%**		**26.56%**	**5.59%**	**6.70%**	**31.82%**	**Av 67°**	**Grey Mudstone Facies-Probably the 113-125m mudstone unit (KNcu2) at Cuskinny Bay (See Appendix A1)**
33											* Palynology sample RC02-DY Box 6-31.3m Med Grey/Med light Grey (N5/6) Siltstone. **See Appendix A2.**
34											****The GCF is distinguished by sandstones containing distinctive scattered rounded vein quartz pebbles.**
35											**In this area, these only occur in the Cuskinny Member (KNcu) and are an important**
36											**stratigraphical marker.**
37											
38	**RC03-DY**	**DEPTH**	**BOX THICKNESS**	**FINE/MED SANDSTONE**	**FLASER**	**SILTSTONE**	**CLAYSTONE**	**LINSEN**	**WEATHERED/BROKEN/GAPS**	**BEDDING DIP**	**NOTES**
39	**RC03-DY BOX 1**	15-18m	3m	70	25			80	125	85°	Extensive fracturing/Qtz filled joints 80°
40	**RC03-DY BOX 2**	18-21m	3m	290					10		Qtz veins/Several joint sets 60°, 70°, 40°, 15°, 20°/St Yellowish Grey 5Y6/2/W2-3
41	**RC03-DY BOX 3**	21-24m	3m	290					10	85°	Yellowish Grey 5Y6/2/Joints 60°, 85°, 45°/W1-2
42	**RCO3-DY BOX 4**	24-27m	3m	240					60		Yellowish Grey 5Y6/2Steep 80°, wide, quartz-veined zone/100cm of St broken/ Joints 50°, 30°, 70°/W1-4
43	**RCO3-DY BOX 5**	27-30m	3m	220					80	85°+	Yellowish Grey 5Y6/2/Joints 80°, 70°, 50°/W2-3
44	**RCO3-DY BOX 6**	30-33m	3m	250					50		Yellowish Grey 5Y6/2/Very broken/Qtz veins
45	**RCO3-DY BOX 7**	33-36m	3m	100					200		Yellowish Grey 5Y6/2/Qtz veins iron weathering/Joints 45°, 70°, 85°
46	**RCO3-DY BOX 8**	36-39m	3m	180	40				80	80°+	Yellowish Grey 5Y6/2/Qtz veins iron weathering/Massive Slightly Lam/Qtz veins 5mm 20°, 45°/
47	**RCO3-DY BOX 9**	39-42m	3m	220					80	90°	Yellowish Grey 5Y6/2/Coarse Brown level **GCF**/Joints Qtz filled 80°, 15°, 30°/Thin Md streaks/W1-2
48	**RC03-DY BOX 10**	42-45m	3m	110	150				40	80-85°	Yellowish Grey 5Y6/2/Qtz filled joints 45°, 50°/Very good lithological contrast in heterolithic unit.
49	**RC03-DY BOX 11**	45-48m	3m	250					50	85-90°	Yellowish Grey 5Y6/2/Mostly massive/Extensive joints c.60°
50	**RC03-DY BOX 12**	48-50m	2m	130					70	45°	Yellowish Grey 5Y6/2/Joints 70° Qtz filled, 80°/strongly jointed/St very massive
51	**TOTALS cm**	3500		2350	215			80	855		**NOTE:Boxes 3-12 are almost identical in their lithological content. This is probably mainly due to the**
52	**TOTALS %**			**67.14%**	**6.14%**			**2.29%**	**24.43%**	**Av 80°**	**very steep bedding dip. Key features are the massive texture and colour.**
53											**The full borehole sequence is probably Kinsale Formation Cuskinny Member (KNcu3)**
54											
55	**RC04-DY**	**DEPTH**	**BOX THICKNESS**	**FINE/MED SANDSTONE**	**FLASER**	**SILTSTONE**	**CLAYSTONE**	**LINSEN**	**WEATHERED/BROKEN/GAPS**	**BEDDING DIP**	**NOTES**
56	**RC04-DY BOX 1**	10.5-13.5m	3m	170					130	75°	Qtz veins 70°/ **GCF (Garyvoe Conglomerate Facies)**/ Med to Coarse St
57	**RC04-DY BOX 2**	13.5-16.5m	3m	230					70	c.60°	1.5m light brown friable St /**GCF**/ 1m long sinuous vertical fracture/?joint 80°
58	**RC04-DY BOX 3**	16.5-19.5m	3m	250					50	80°	Joint c.70°
59	**RCO4-DY BOX 4**	19.5-22.5m	3m	170	20				110		Qtz vein/?faulting adjacent
60	**RCO4-DY BOX 5**	22.5-25.5m	3m	180	40				80		Qtz veins/ Intersecting joint sets 55-65°/ joint 75 °
61	**RCO4-DY BOX 6**	25.5-28.5m	3m	255					45		Qtz/Joints 30° & 70° intersecting sets/All med St
62	**RC04-DY BOX 7**	28.5-32.5m	4m	90					210		Qtz filled joint 45°/?fault/strongly weathered zone locally
63	**RC04-DY BOX 8**	32.5-37.5m	5m	70					230	c.60°	Qtz vein ?Fault zone
64	**RCO4-DY BOX 9**	37.5-40m	2.5m	80	10				210	c.65°	Qtz vein c.70°/Heavily weathered zone locally
65	**TOTALS cm**	2950		1495	70				1135		**NOTE: Boxes 1-9 are Kinsale Formation Cuskinny Member (KNcu3).**
66	**TOTALS %**			**55.37%**	**2.59%**				**42.04%**	**Av 68°**	
67											**NOTE: ALL THICKNESSES ARE IN CENTIMETRES UNLESS OTHERWISE STATED**
68											
69											**ABBREVIATIONS**
70											St-Sandstone, Slt-Sitlstone, C-Claystone, Md-Mudstone (i.e. Siltstone and Claystone combined)
71											Qtz-Quartz, J-Joint, Lam-Laminated, Med-Medium, N1 etc-Goddard Colour Code
72											W1 etc-Weathering Grades,

Fig 7.3. Summary of bedrock geological characteristics of RC01-DY to RC04-DY. Depth shown is bgl. 'Broken' refers to NI-Non-Intact pieces. See summary bar charts for lithologies below.

	A	B	C	D	E	F	G	H	I	J	K
1	**RC05-DY**	**DEPTH**	**BOX THICKNESS**	**FINE/MED SANDSTONE**	**FLASER**	**SILTSTONE**	**CLAYSTONE**	**LINSEN**	**WEATHERED/BROKEN/GAPS**	**BEDDING DIP**	**NOTES**
2	**RC05-DY BOX 1**	7.5-13m	5.5m	65					485		Yellow grey (5Y6/2) St
3	**RC05-DY BOX 2**	13-16m	3m			230			70	60°	Very fine Slt/ Fractured/Grey N4-5/Fractures 70-80° ?Cleavage/W2-3/**Grey Mudstone Facies**
4	**RC05-DY BOX 3**	16-19m	3m			45	110		145	45-50°	Slt fine grained Grey N3-4/W2-3
5	**RCO5-DY BOX 4**	19-22m	3m	40		90		10	160	25°	St Brown intensely weathered W4 & contains **GCF***/Slt is very fine grained **Grey Mudstone Facies**/W1-2/N4/Total Slt 250 incl broken
6	**RCO5-DY BOX 5**	22-25m	3m	125	20			10	145	20-30°	St Light Grey N7 to Yellow Gy 5Y7/2/Much disruption and folding of layers due to synsedimentary processes
7	**RCO5-DY BOX 6**	25-28m	3m	150	75				75	30°	St Light Grey N7/ Very good separation in Flaser/W1-2
8	**RC05-DY BOX 7**	28-31m	3m	180	40				80	40°	St 5Y6/2 & N6/30cm of St friable (W4-5) otherwise W1-2/ Joints 75° & 85° sets some Qtz filled/Good separation in Flaser
9	**RC05-DY BOX 8**	31-34m	3m	110	90	60			40	35°	9 Qtz filled joints in St 60°/ St Light Olive Grey 5Y6/1 and W1/Slt Grey N3-4 and W3
10	**RC05-DY BOX 9**	34-37m	3m		60	230			10	38°	Slt Fine Grained with thin coarser laminae/**Grey Mudstone Facies**/W1-2/ *Palynology sample RC05-DY Box 9-35.75m Fine Siltstone
11	**RC05-DY BOX 10**	37-40m	3m	280				20	55	35°	St includes 8cm **GCF**/St Grey N6/Joints 50°, 60°, 70°, 90°/W2-3
12	**TOTALS cm**		3250cm	950	285	655	110	40	1265		**NOTE: The presence of the GCF along with the other lithologies indicates that this is Cuskinny Member (KNcu)**
13	**TOTALS %**			**28%**	**8.62%**	**19.82%**	**3.33%**	**1.21%**	**38.28%**	**Av 37°**	**See Appendix A2.**
14											
15											
16	**RC06-DY**	**DEPTH**	**BOX THICKNESS**	**FINE/MED SANDSTONE**	**FLASER**	**SILTSTONE**	**CLAYSTONE**	**LINSEN**	**WEATHERED/BROKEN/GAPS**	**BEDDING DIP**	**NOTES**
17	**RC06-DY BOX 1**	8.5-11.5m	3m			270			30	30-40°	Abundant fracturing along bedding/Fine Siltstone N4/W2/Cleavage 70-80°/**Grey Mudstone Facies**
18	**RC06-DY BOX 2**	11.5-14.5m	3m			300			90	35°	Abundant fracturing along bedding/Fractures 80°/Fine Siltstone N4/W2/**Grey Mudstone Facies**
19	**RC06-DY BOX 3**	14.5-17.5m	3m	75	70	40		70	40	40°	Strongly fracturing along bedding/St Med-Coarse Brown W1-2/Slt N3 Very Fine & Soft/Linsen N3-4/**GCF 45cm**/ W4/ Mod Yellow Brown
20	**RCO6-DY BOX 4**	17.5-20.5	3m	240	45				15	15-20°	Fracturing along bedding/1m of heavily weathered brown St W4/**GCF (Garryvoe Conglomerate Facies*)**
21	**RCO6-DY BOX 5**	20.5-23.5m	3m	260	30				10	30°	Fracturing along bedding/ Extensive quartz veins in joints 70-80°/Of sand, 60cm is broken with thin md streaks
22	**RCO6-DY BOX 6**	23.5-26.5m	3m	210	70				10	20-25°	Pale greenish grey St/W1-2/25cm Quartz vein within sandstone
23	**RC06-DY BOX 7**	26.5-29.5m	3m	230	70					30-40°	Qtz veins vertically associated with 10cm **GCF**/ Scattered Md lam in St/St N6-7/W2
24	**RC06-DY BOX 8**	29.5-32.5m	3m		265	35			15	c10-20°	Thin Qtz veins in joints 70°/Two sets intersecting/Flaser N6/ Slt N2-3/Sedimentary deformation of layers/W2
25	**RCO6-DY BOX 9**	32.5-35m	2.5m	170	60		40		10	c10-15°	40 St with Md streaks and 4 local flasers/Several Qtz filled joints 70°/St N5-6 W1-2/Flaser contains **GCF** N4-5/Clay fractured
26	**TOTALS cm**		2650cm	1185	610	645	40	70	220		**NOTE: The presence of the GCF along with the other lithologies indicates that this is Cuskinny Member (KNcu)**
27	**TOTALS %**			**42.78%**	**22.02%**	**23.29%**	**1.44%**	**2.53%**	**7.94%**	**Av 27°**	
28											
29											
30	**RC07-DY**	**DEPTH**	**BOX THICKNESS**	**FINE/MED SANDSTONE**	**FLASER**	**SILTSTONE**	**CLAYSTONE**	**LINSEN**	**WEATHERED/BROKEN/GAPS**	**BEDDING DIP**	**NOTES**
31	**RC07-DY BOX 1**	5.7-8.3m	2.6m	170					90	40°	Minor Qtz veins/Thin mud layers
32	**RC07-DY BOX 2**	8.3-11m	2.7m	50	50	70			100	40-50°	10cm thick coarse laminations in flaser
33	**RC07-DY BOX 3**	11-13.7m	2.7m					265	5	30°	70-90% of Slt in linsen/Weathering along Joint 50°/ *Palynology sample RC07-DY Box 3-11.5m Med Grey (N5) Siltstone
34	**RCO7-DY BOX 4**	13.7-16.5m	2.8m			165		95	20	35-40°	W1/Fracture 75° ?Joint/Linsen 95% Siltstone/Siltstone Fine Grained N3-4 and Soft
35	**RCO7-DY BOX 5**	16.5-19.5m	3m	115	135				50	25°	Qtz veins 70°. Oxidised zones/GCF* 2cm coarse quartz grains/c.10cm coarse sandstone
36	**RCO7-DY BOX 6**	19.5-22.3m	2.8m	155	75				50	30°	Qtz veins 70° Coarse sandstone levels 10cm/**GCF (Garryvoe Conglomerate Facies***)
37	**RC07-DY BOX 7**	22.3-25.9m	3.6m	90					270		Strongly weathered and broken/ ?fault zone
38	**RC07-DY BOX 8**	25.9-30.5m	4.6m	215	20				225	40°	Thin Qtz veins 75-80°/35cm coarse level in sandstones
39	**RCO7-DY BOX 9**	30.5-32m	150cm	110	10				30		Qtz veins 75°/Thin mud laminations
40	**TOTALS cm**			905	290	235		360	840		
41	**TOTALS %**			**34.41%**	**11.03%**	**8.94%**		**13.69%**	**31.94%**	**Av 36°**	**Boxes 1-9 are probably all in the Cuskinny Member (KNcu).**
42											**See Appendix A2.**
43											
44	**RC08-DY**	**DEPTH**	**BOX THICKNESS**	**FINE/MED SANDSTONE**	**FLASER**	**SILTSTONE**	**CLAYSTONE**	**LINSEN**	**WEATHERED/BROKEN/GAPS**	**BEDDING DIP**	**NOTES**
45	**RC08-DY BOX 1**	13.5-18.2m	4.7m			110			360	50°	Siltstone Grey N2-4
46	**RC08-DY BOX 2**	18.2-20.8m	2.6m					175	85	50°	Palynology sample RC08-DY Box 2-20.2m Medium Grey (N2-3) Siltstone/W1-2
47	**RC08-DY BOX 3**	20.8-23.4m	2.6m			250			10		
48	**RC08-DY BOX 4**	23.4-26.2m	2.8m			195			70	50°	**Grey Mudstone Facies** (i.e. as found in KNcs, KNpc or mud units within KNcu)/N3-5/Slt Fine Grained/70cm long 80°+ fracture/W1-2
49	**RC08-DY BOX 5**	26.2-29.2m	3m		30	135			135	35-40°	**Grey Mudstone Facies** /*Palynological sample RC08-DY Box 5-28.5m Dark to Medium Dark Grey (N3/4) Siltstone
50	**RC08-DY BOX 6**	29.2-32.1m	2.9m					260	30	30-40°	40-50% Sandstone-Siltstone laminations
51	**RC08-DY BOX 7**	32.1-34.8m	2.7m					260	10	45°	20-25% Sandstone-Siltstone laminations, burrowed
52	**RC08-DY BOX 8**	34.8-37.7m	2.9m		90	180		10	10	40°	**Grey Mudstone Facies**/Iron stained subvertical joint/Joints 82-85°
53	**RC08-DY BOX 9**	37.7-41.5m	3.8m			270			110		90% of fine Siltstone is **Grey Mudstone Facies**/*Palynological sample RC08-DY Box 9-38.5m Medium Grey (N5) Siltstone
54	**RC08-DY BOX 10**	41.5-44.6m	3.1m		240				70	35°	c.50% St/Slt ratio in flaser units
55	**RC08-DY BOX 11**	44.6-45.7m	1.1m		75				35	35°	
56	**TOTALS cm**	3220			435	1140		705	925		
57	**TOTALS %**				**13.57%**	**35.57%**		**22.00%**	**28.86%**	**Av 42°**	**The sequence in this borehole is possibly a finer unit within the Cuskinny Member (KNcu4). See Appendices A1 and A2.**
58											
59											***The GCF is distinguished by sandstones containing scattered rounded**
60											**vein quartz pebbles. In this area, these only occur in the Cuskinny Member (KNcu)**
61											**and are an important stratigraphical marker.**
62											
63											**NOTE: ALL THICKNESSES ARE IN CENTIMETRES UNLESS OTHERWISE STATED**
64											
65											

Fig 7.4. Summary of bedrock geological characteristics of RC05-DY to RC08-DY. Depth shown is bgl. 'Broken' refers to NI-Non-Intact pieces. See summary bar charts for lithologies below.

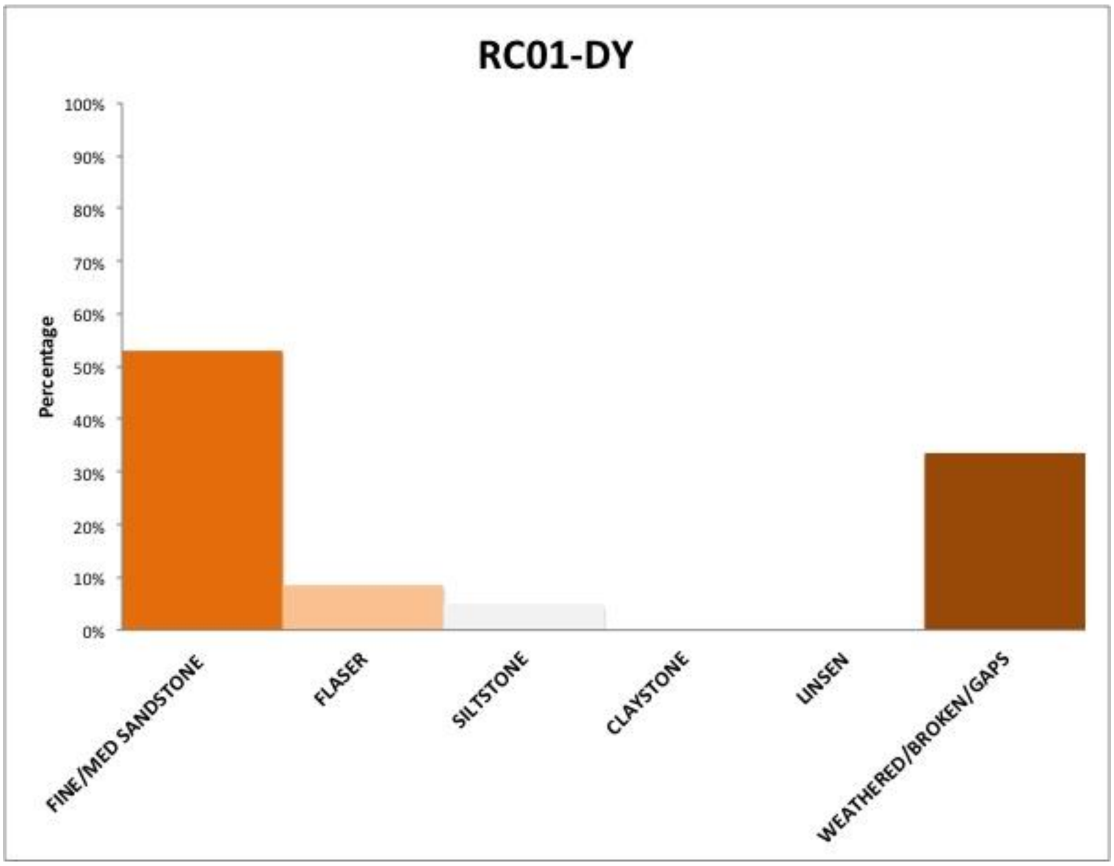


Fig 7.5. Histogram of lithologies in RC01-DY (Kinsale Formation Cuskinny Member).

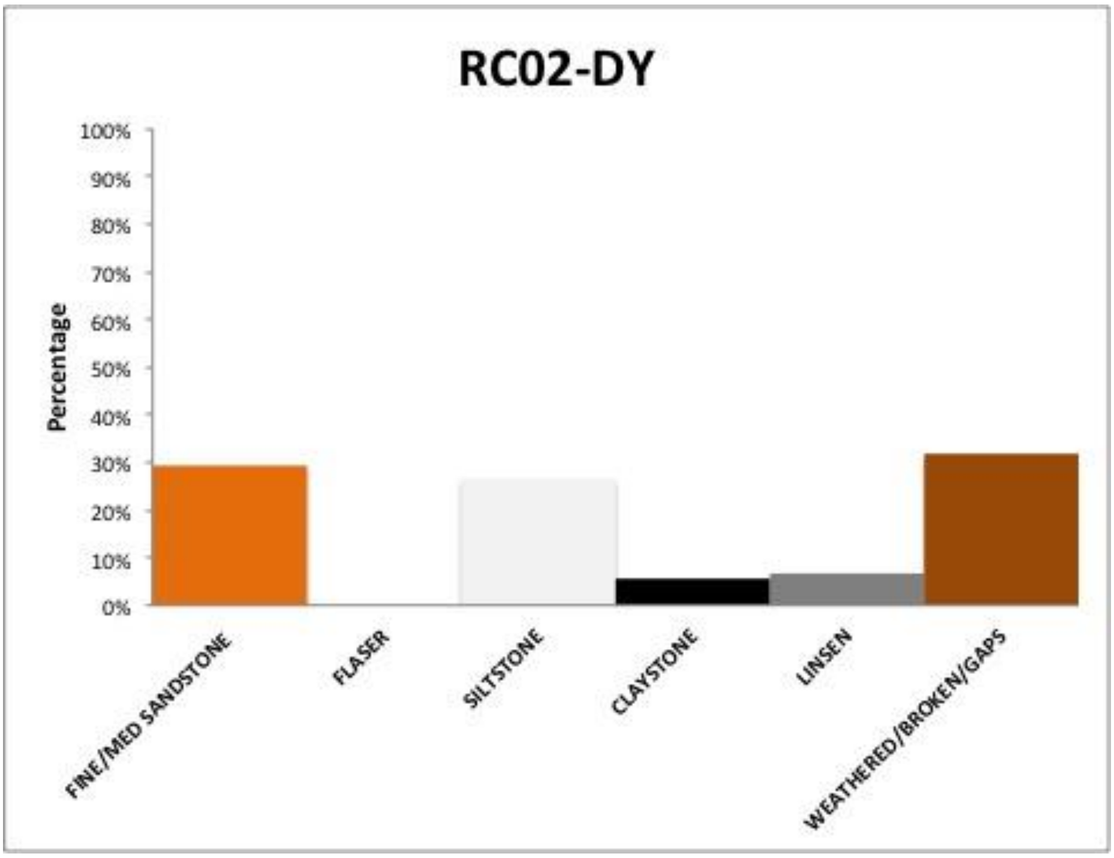


Fig 7.6. Histogram of lithologies in RC02-DY (Kinsale Formation Cuskinny Member).

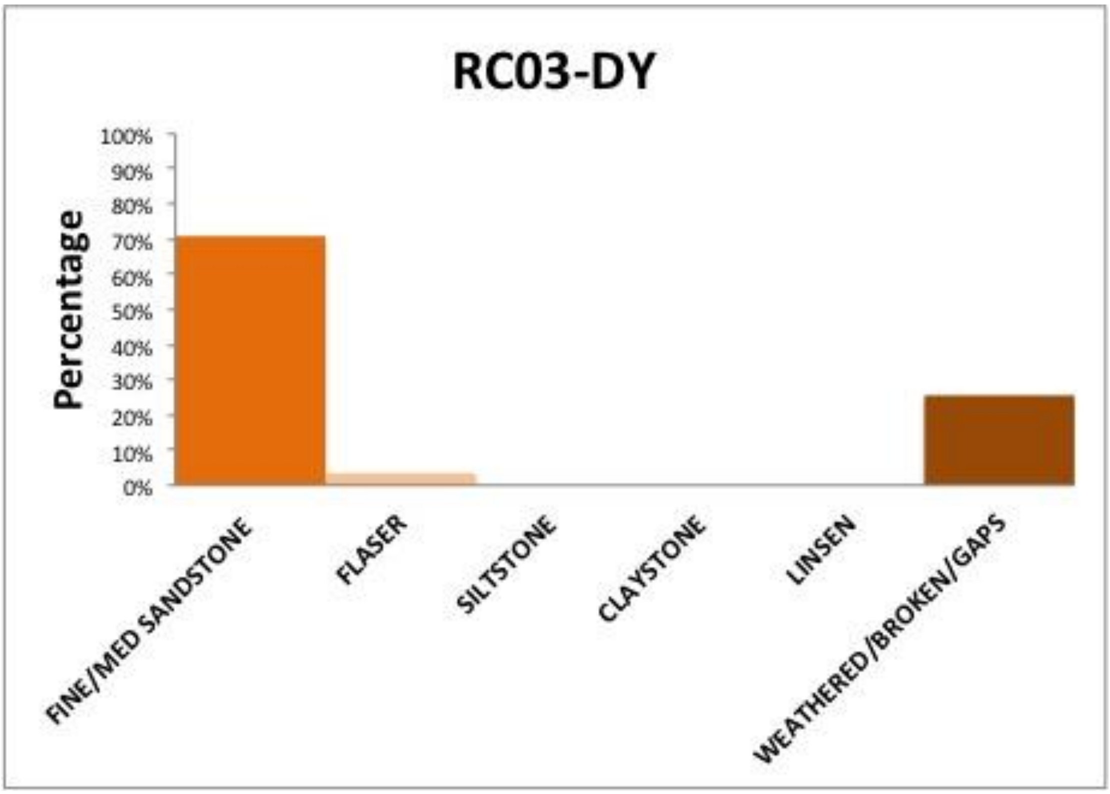


Fig 7.7. Histogram of lithologies in RC03-DY.

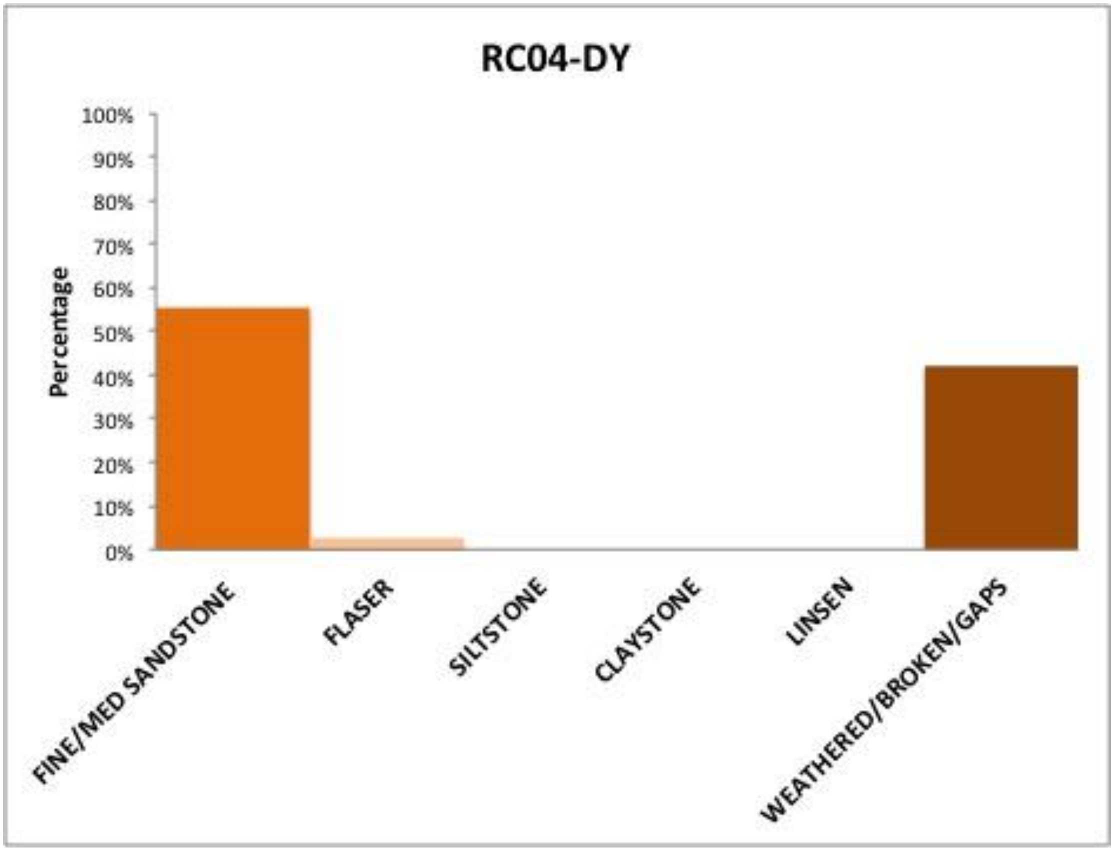


Fig 7.8. Histogram of lithologies in RC04-DY (Kinsale Formation Cuskinny Member).

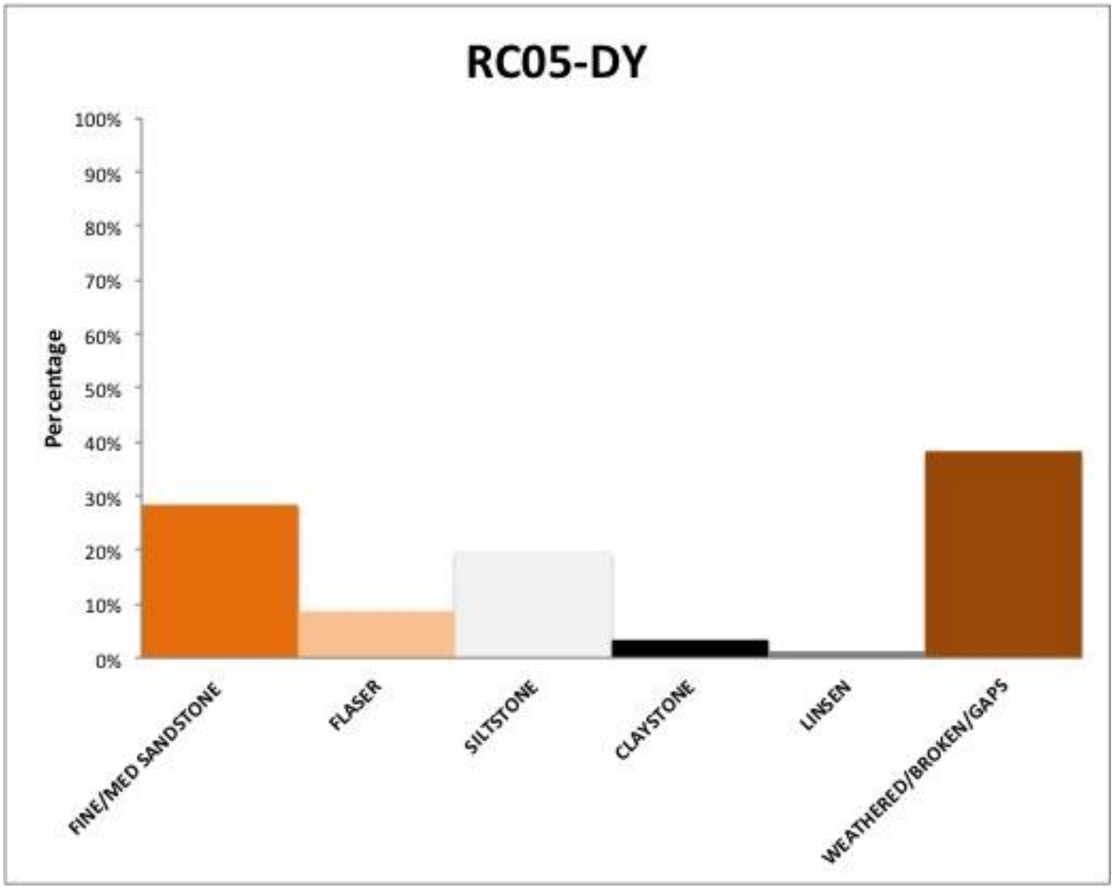


Fig 7.9. Histogram of lithologies in RC05-DY (Kinsale Formation Cuskinny Member).

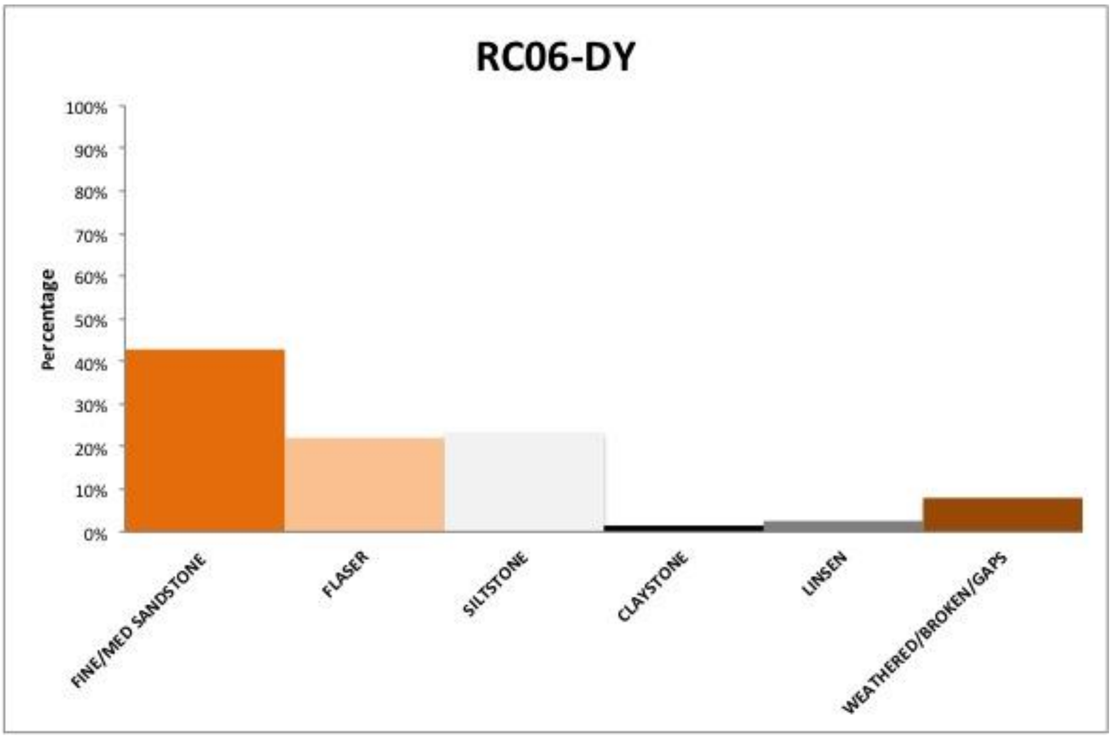


Fig 7.10. Histogram of lithologies in RC06-DY (Kinsale Formation Cuskinny Member).

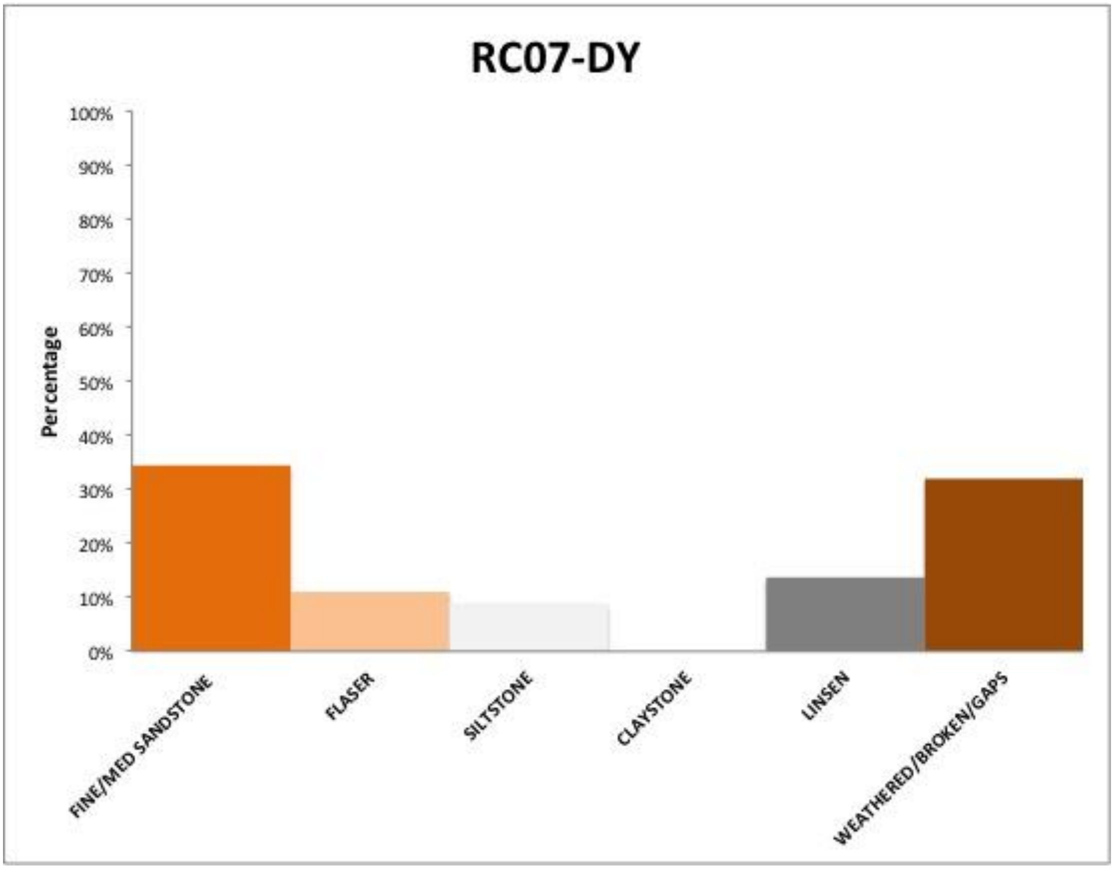


Fig 7.11. Histogram of lithologies in RC07-DY (Kinsale Formation Cuskinny Member).

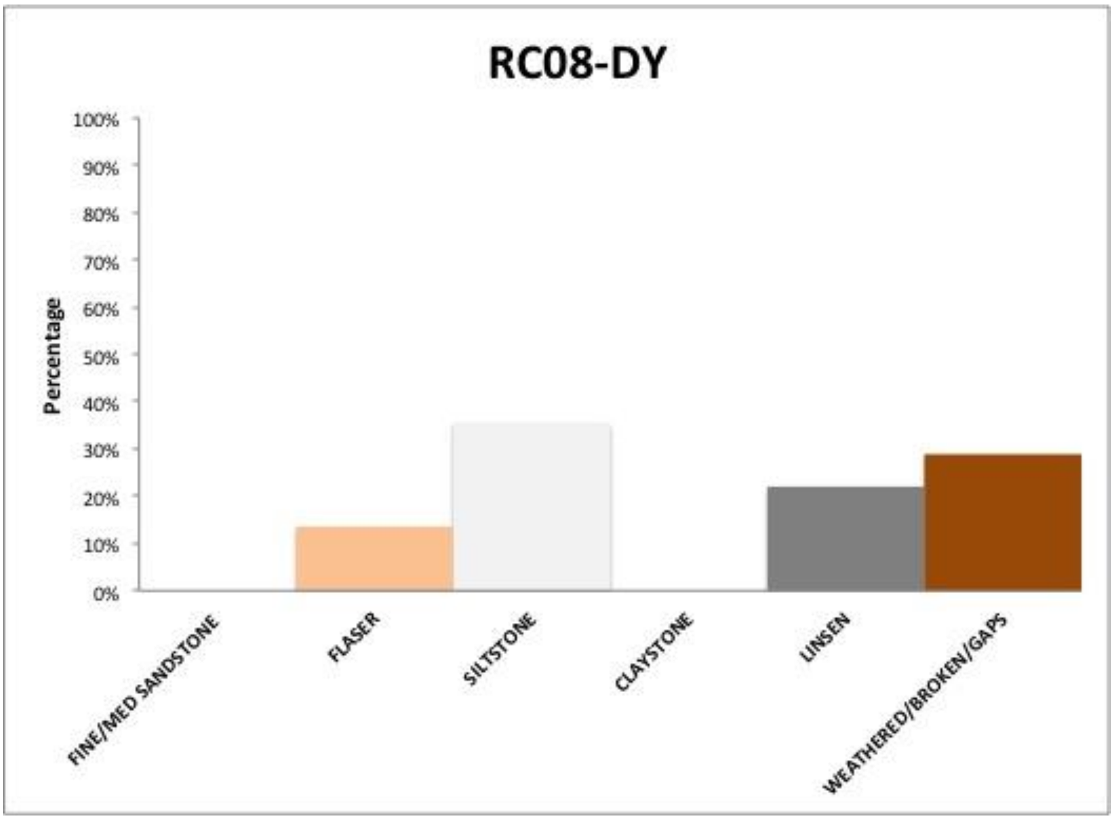


Fig 7.12. Histogram of lithologies in RC08-DY (Kinsale Formation Cuskinny Member).

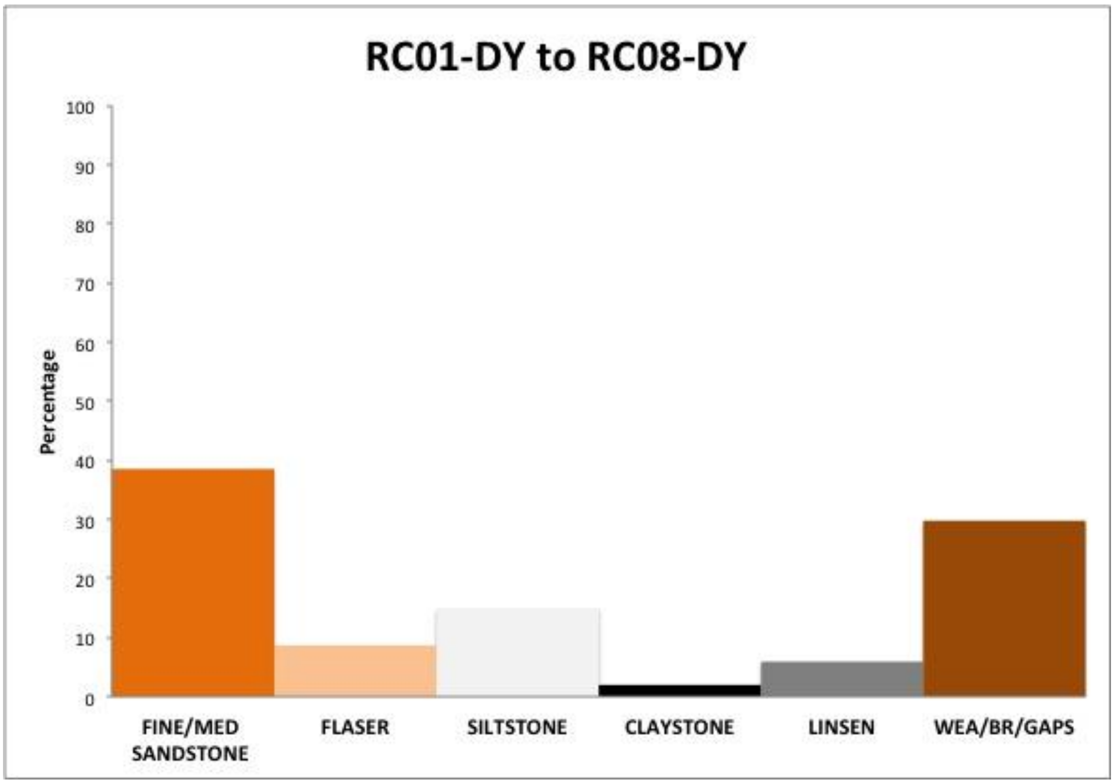


Fig 7.13. Summary histogram of lithologies in RC01-DY to RC08-DY (Kinsale Formation Cuskinny Member) including weathered/broken (NI)/gaps.

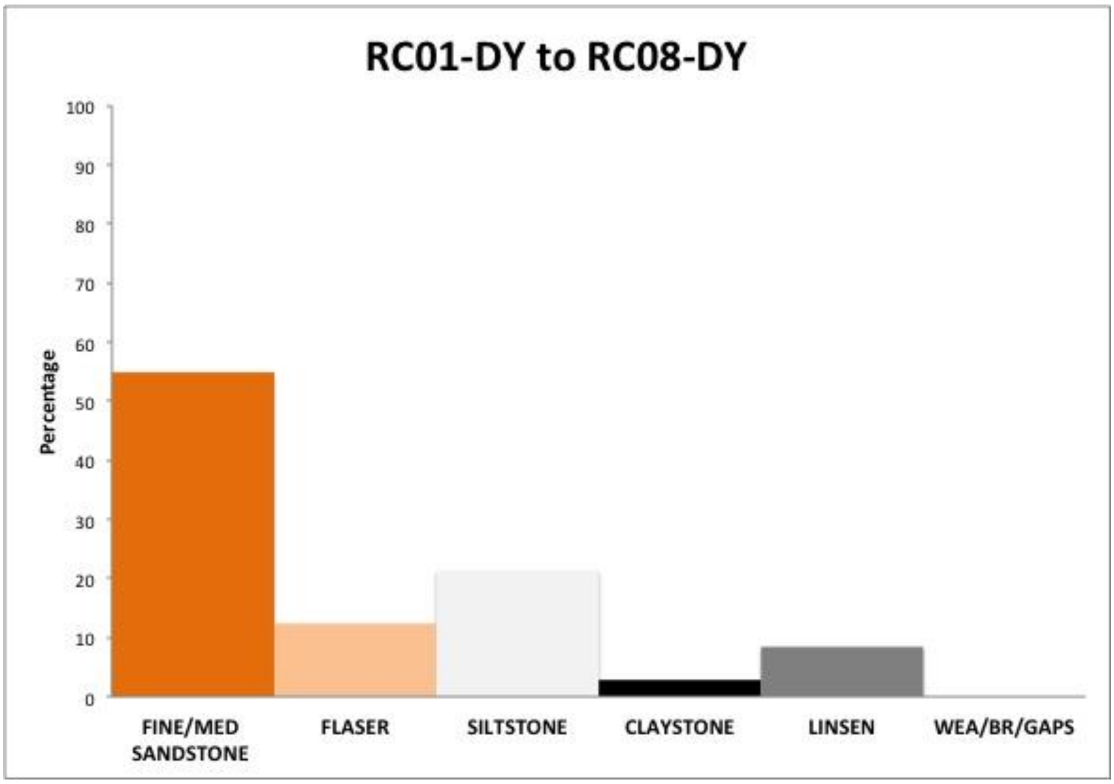


Fig 7.14. Summary histogram of lithologies in RC01-DY to RC08-DY (Kinsale Formation Cuskinny Member) excluding weathered/broken (NI)/gaps.

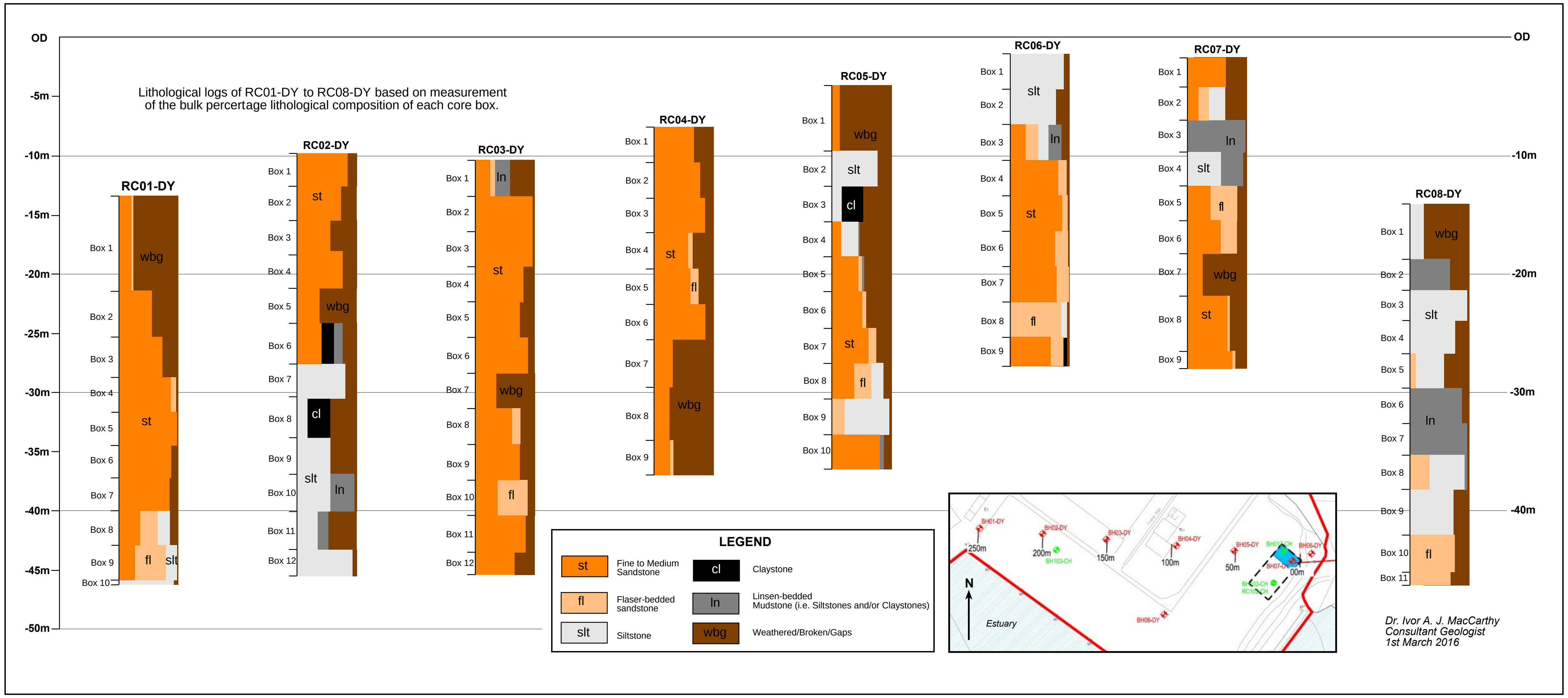


Fig 7.15. Composite summary histogram logs of lithological composition of RC01-DY to RC08-DY. The individual segments that comprise each borehole in the drawing depict the lithological composition in each core box.

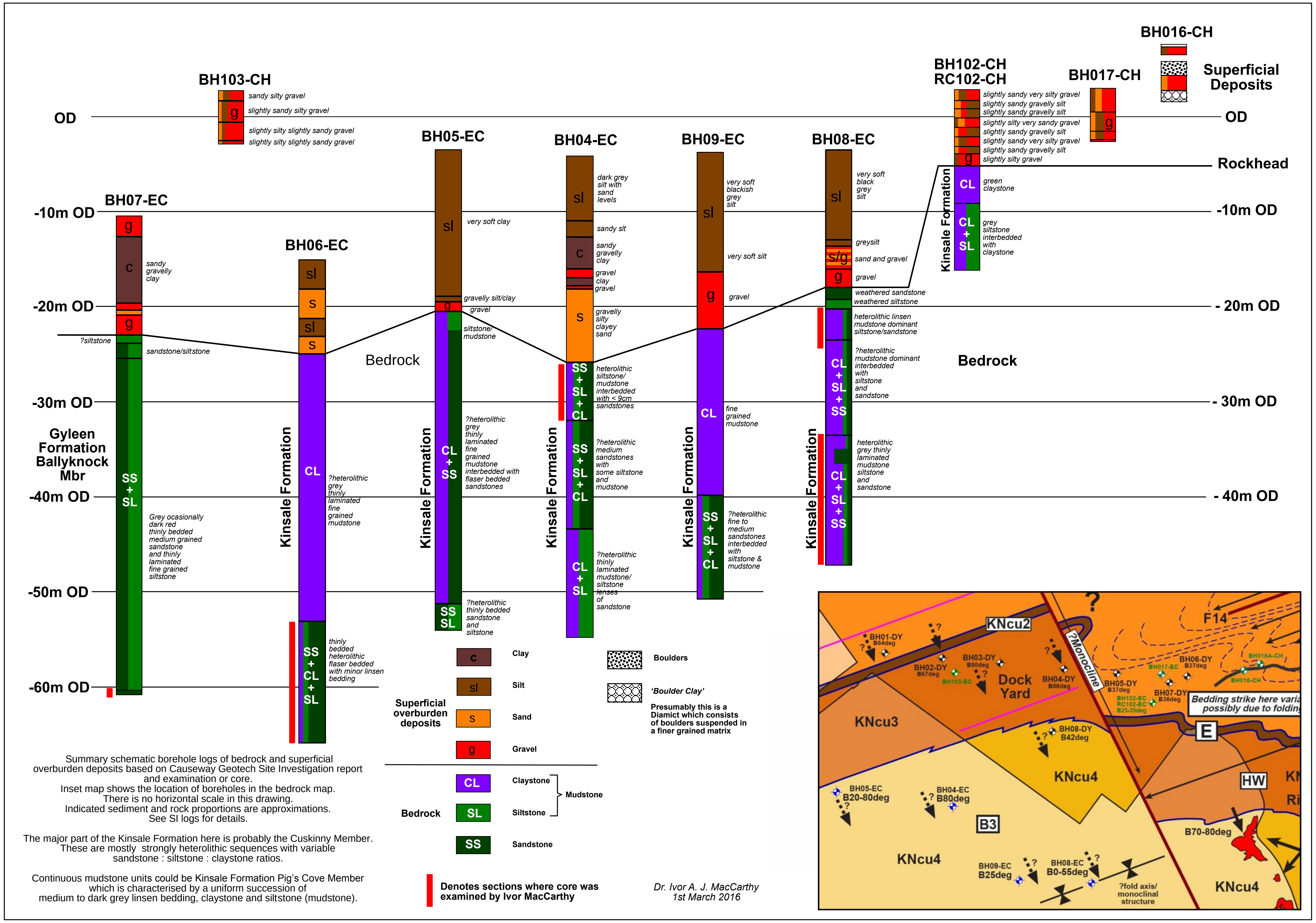


Fig 7.16. Summary schematic logs of offshore boreholes (BH04-EC to BH09-EC) and onshore boreholes (BH016-EC, BH017-EC, BH102-EC and BH103-EC) through the bedrock and superficial deposits in the Cork Dockyard area. The *Claystones* here were listed as *Mudstone* in the original logs. The difference here is solely one of terminology. The term *Mudstone* in this report is a class term for Claystone and Siltstone combined. Much the claystones shown in this formation here are probably Clayey Siltstones or Silty Claystones, with varying percentages of clay material, rather than pure Claystones.

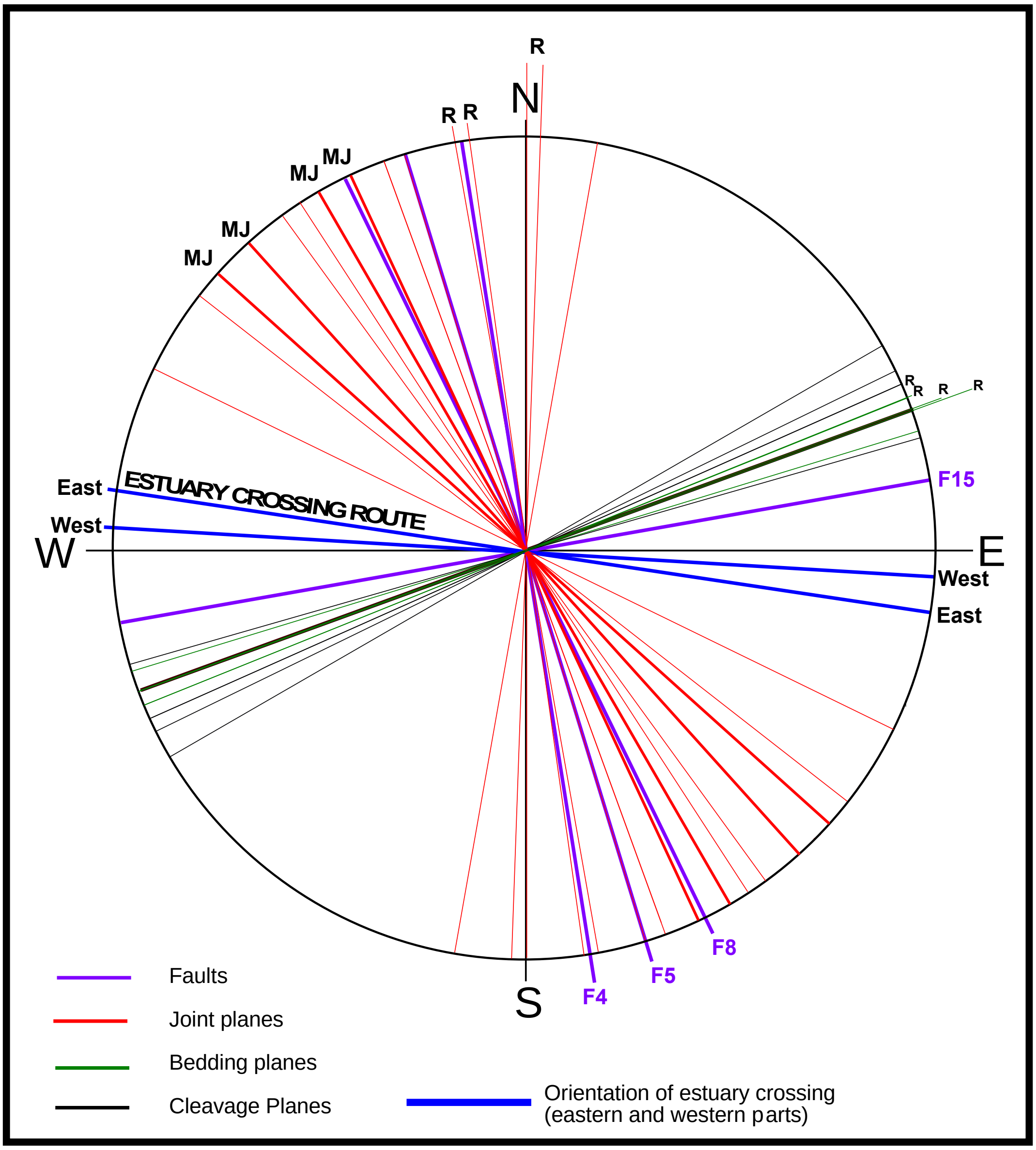


Fig 7.17. Strike orientations of discontinuities in the bedrock (Kinsale Formation) at Ringacoltig and Rushbrooke Railway cutting (R) in relation to the orientation of the estuary crossing. The orientations of the various discontinuities in the crossing (particularly to the east of Fault F5 in Fig 6.2) are likely to be broadly similar to those shown here. Joints dip at c.70-85°. Cleavage planes and fracture cleavage planes dip at c.82-85°. Bedding planes dip at c.50-80°. MJ-Master joints. See data in Appendix A4. F4 and F5 - Important vertical/sub-vertical faults.

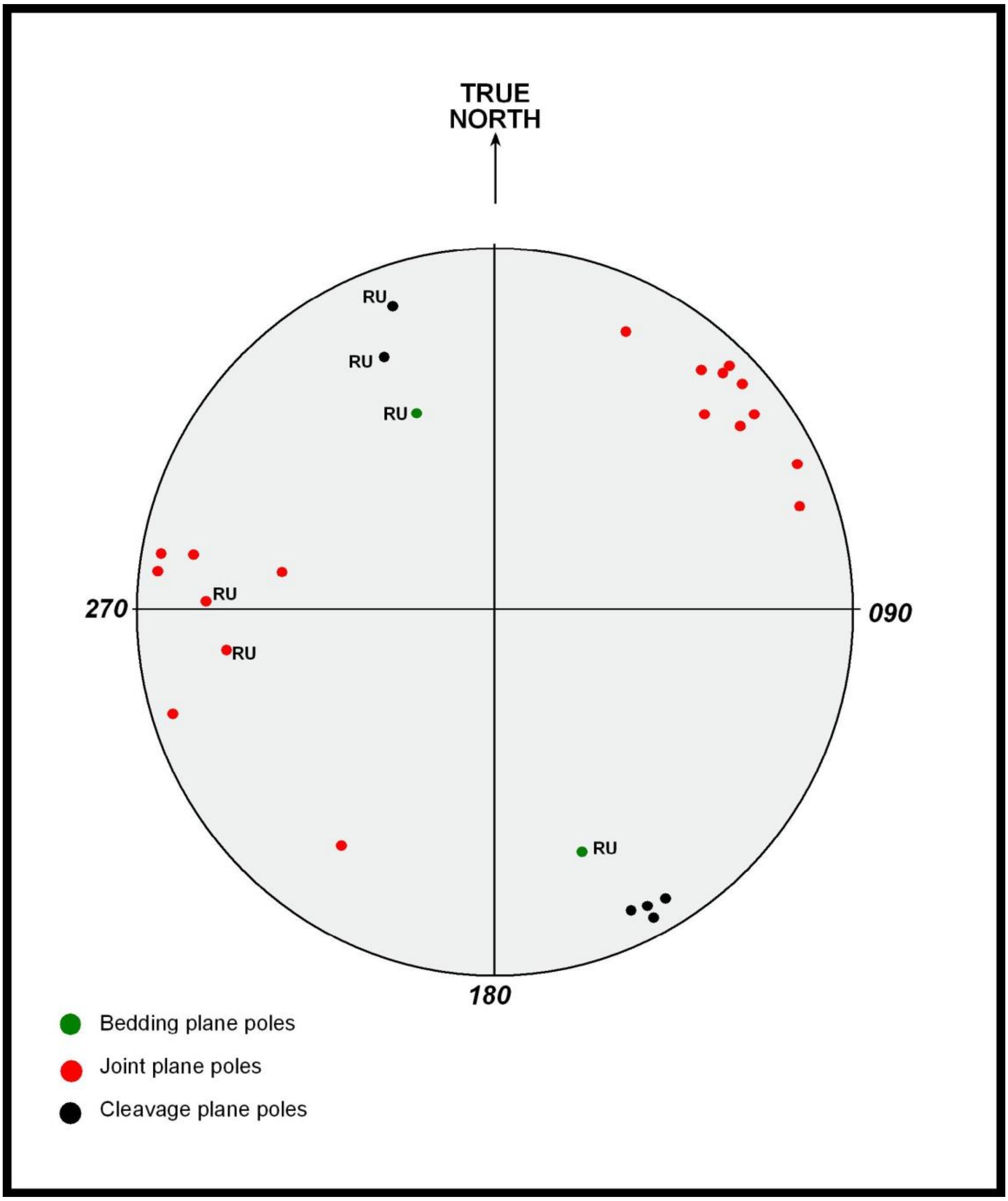


Fig 7.18. Stereographical projections of poles of representative bedding, joint and cleavage planes in the bedrock (Cuskinny Member) at Ringacoltig and Rushbrooke Railway (RU). See data in Appendix A4.

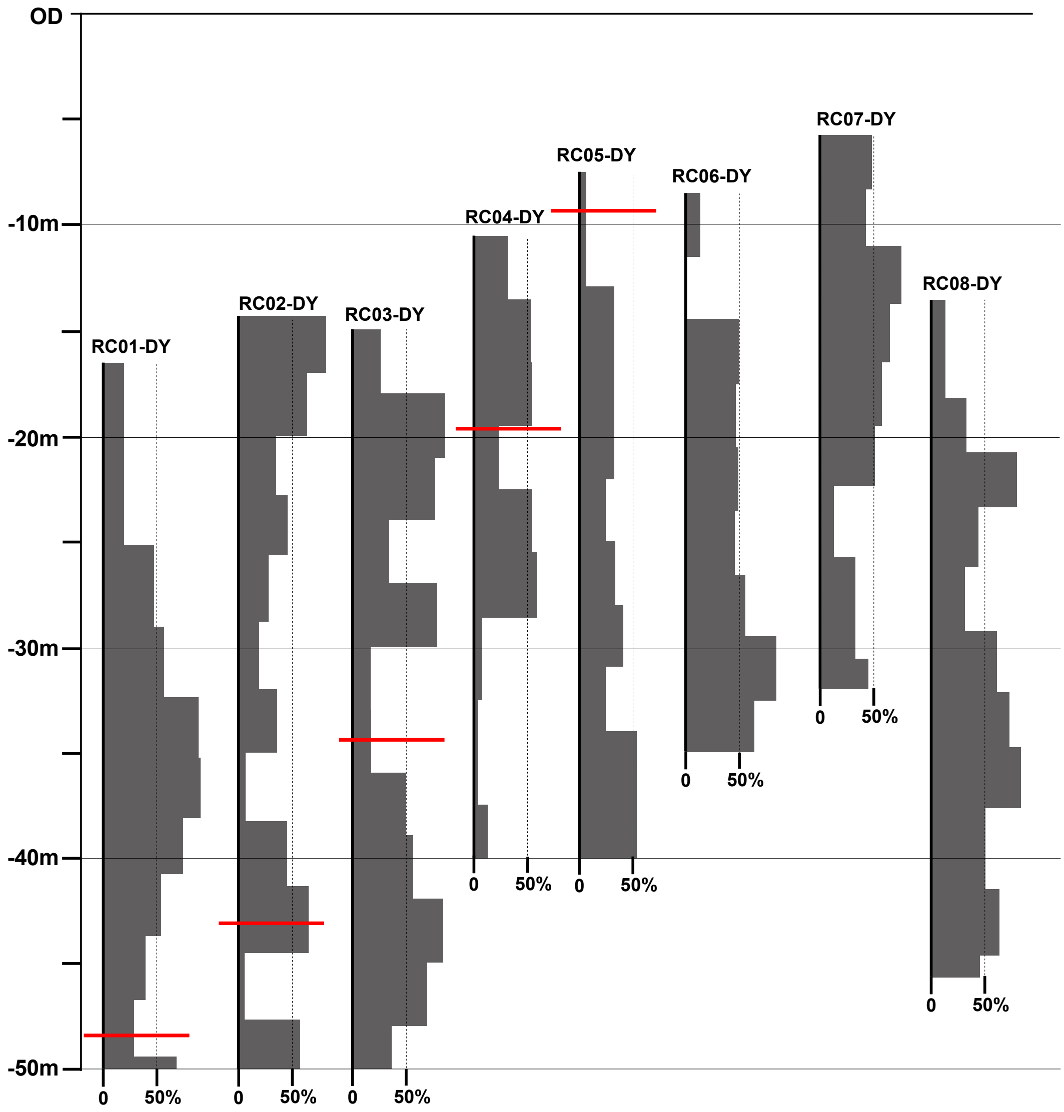


Fig 10.1. Cumulative histograms showing approximate percentage of solid core equal to or greater than 100mm in length relative to the depth drilled for each core box in the Cork Dockyard area (i.e. RQD). Each vertical segment within each borehole represents the calculation for a single core box. These calculations are based on examination of core photographs in the submission dated 14th December 2015. Note the high proportion of the core showing an RQD of less than 50%. Red lines show approximate drill level.

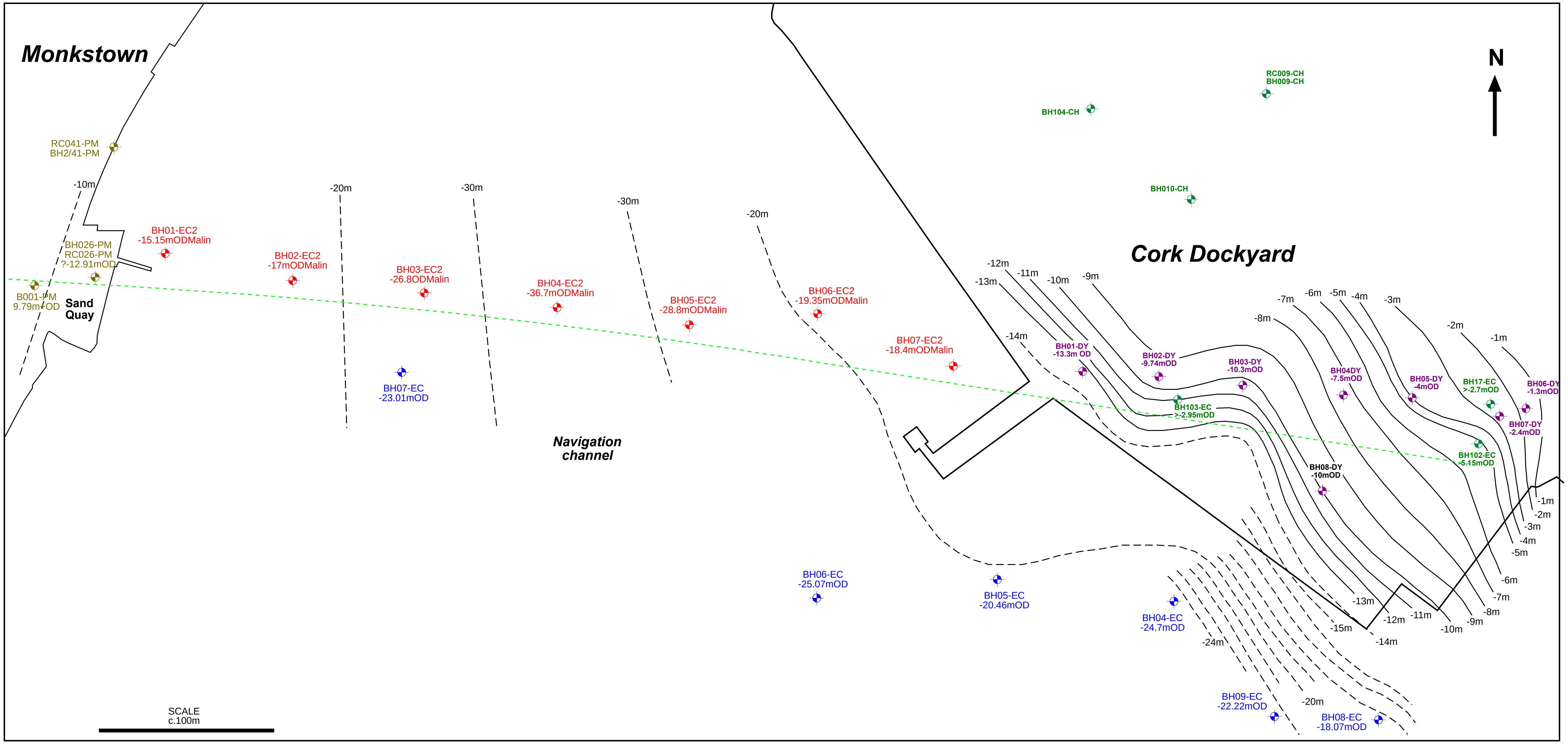


Fig 11.1. Interpreted contours of the rockhead in the Cobh-Monkstown estuary crossing area based on borehole data. Contour values in mOD. Contour lines drawn between boreholes are speculative. The green line represents the estuary crossing.

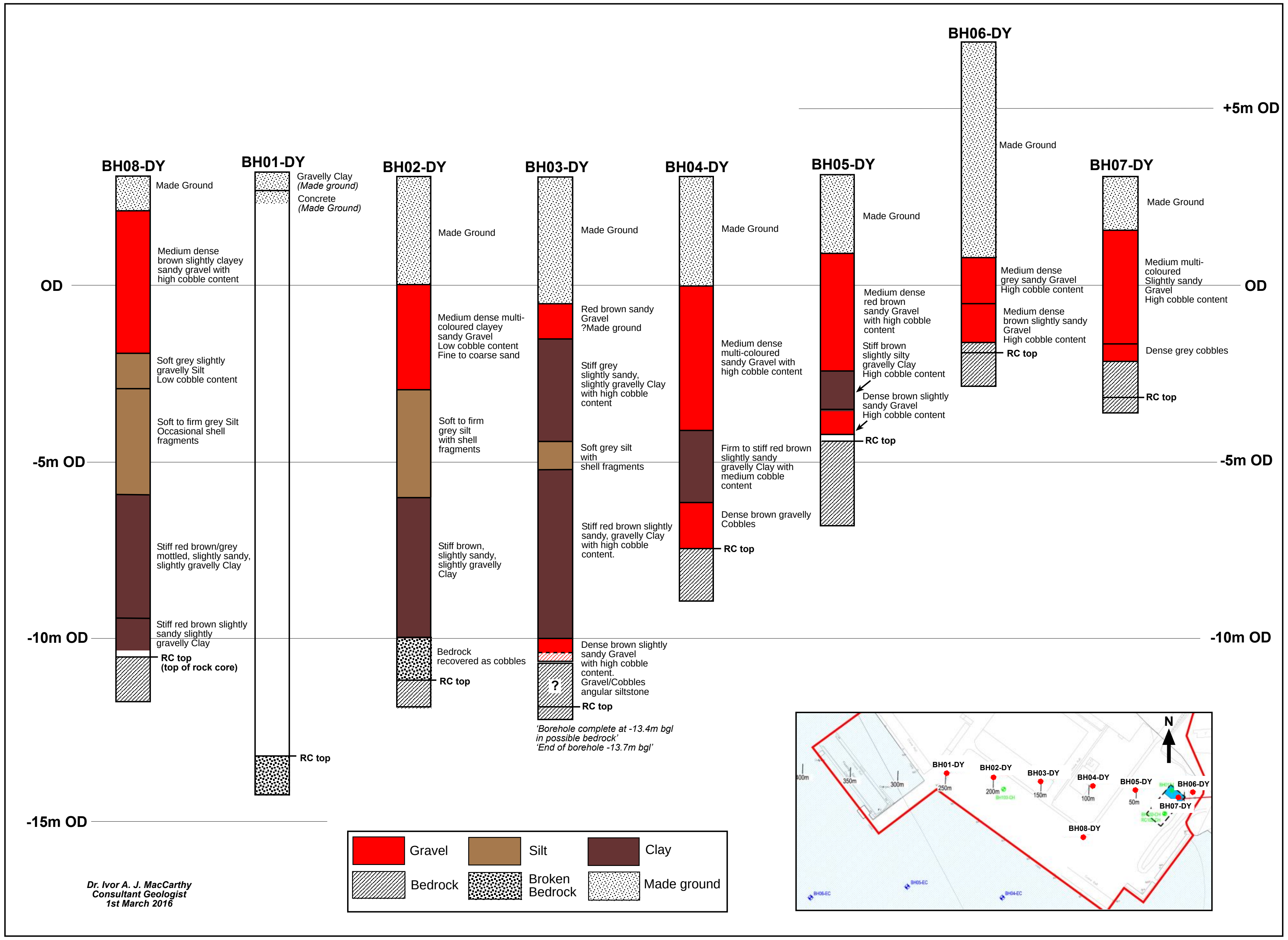


Fig 12.1. Simplified summary borehole logs of the superficial deposits
in Boreholes BH02-DY to BH08-DY. The superficial deposits in the available SI logs for
BH01-DYdid not contain a detailed description of this section.
RC top - Top of the recovered rock core.
See Fig 7.16 for details of BH016-CH, BH017-CH, BH102-CH and BH103-CH.

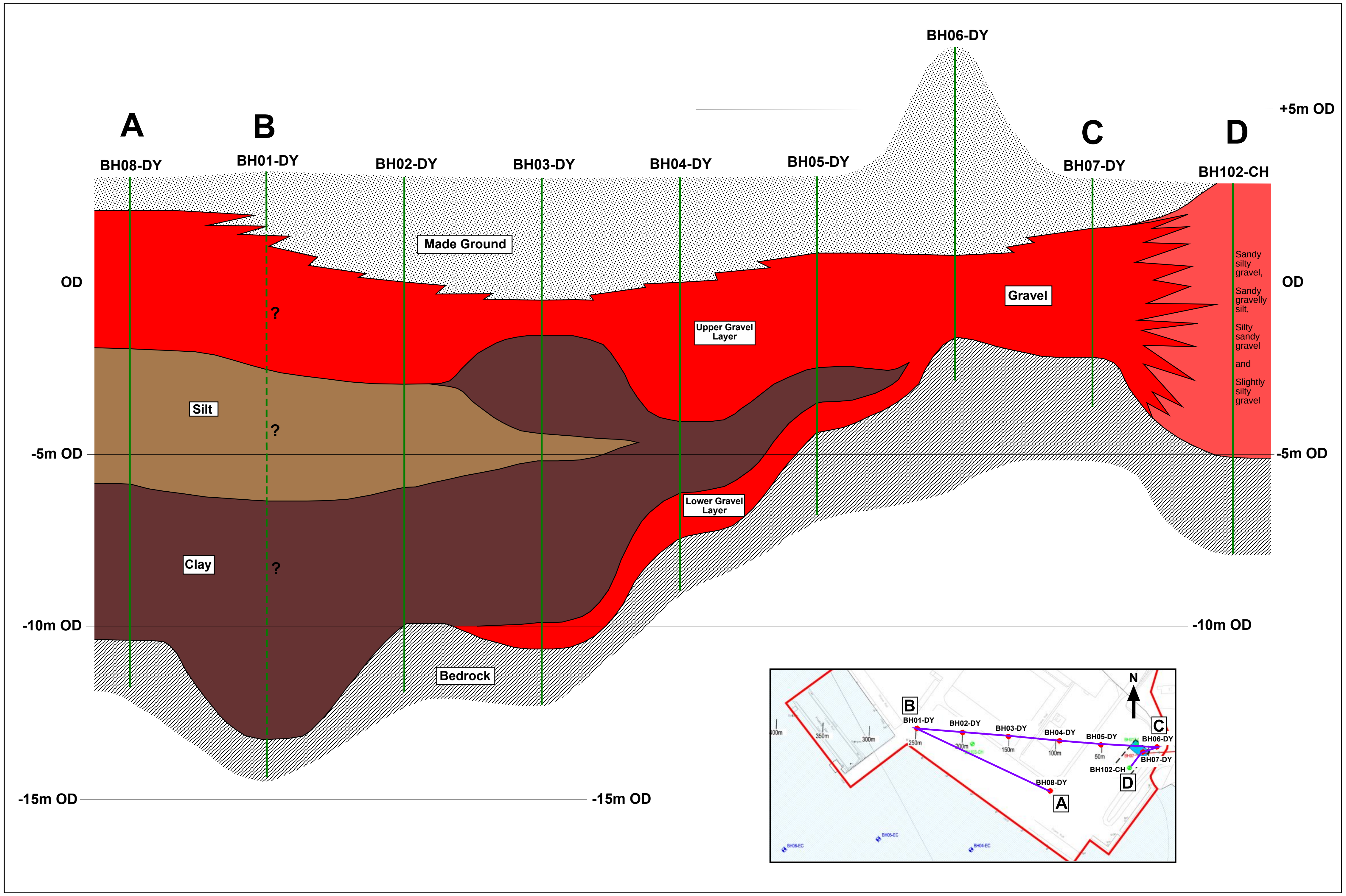


Fig 12.2. Simplified distribution pattern of the superficial deposits
in Boreholes BH02-DY to BH08-DY and BH102-CH. The superficial deposits SI logs for BH01-DY do not contain a detailed description of the section.

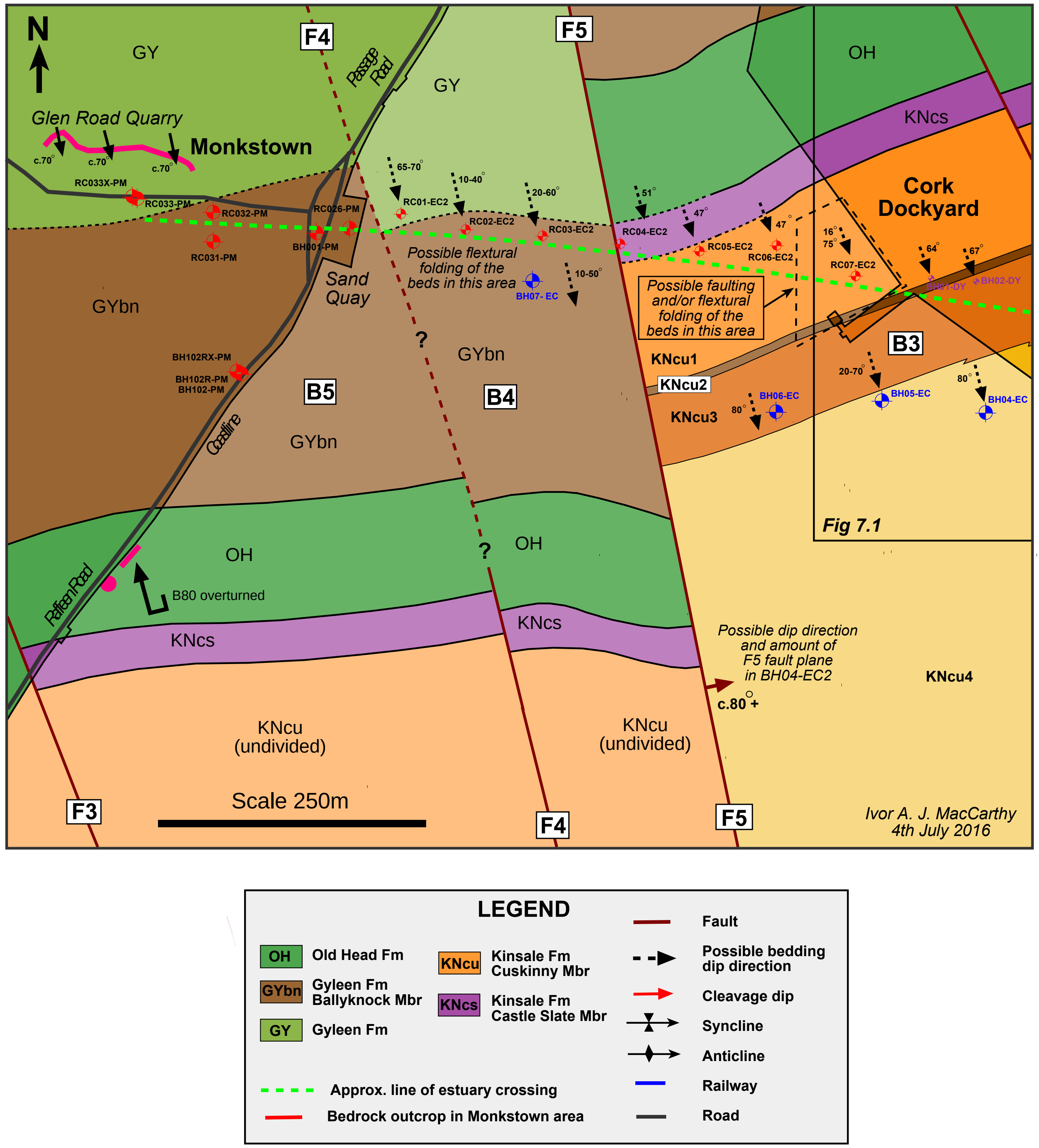


Fig 13.1a. Detailed map of the bedrock geology of the Cobh-Monkstown estuary crossing area (Model 1).
The Kinsale Formation is subdivided into four units (KNcu1-KNcu4) in the area to the east of Fault F5.
NOTE: The directions of bedding dip in the offshore and Cork Dockyard areas are speculative. They are based on the regional structural trend.
Deviations from these are highly possible and to be expected. Folding and more gentle flexuring of the beds are probably present throughout Blocks B3 and B4.
See detailed stratigraphical legend in Page 70.

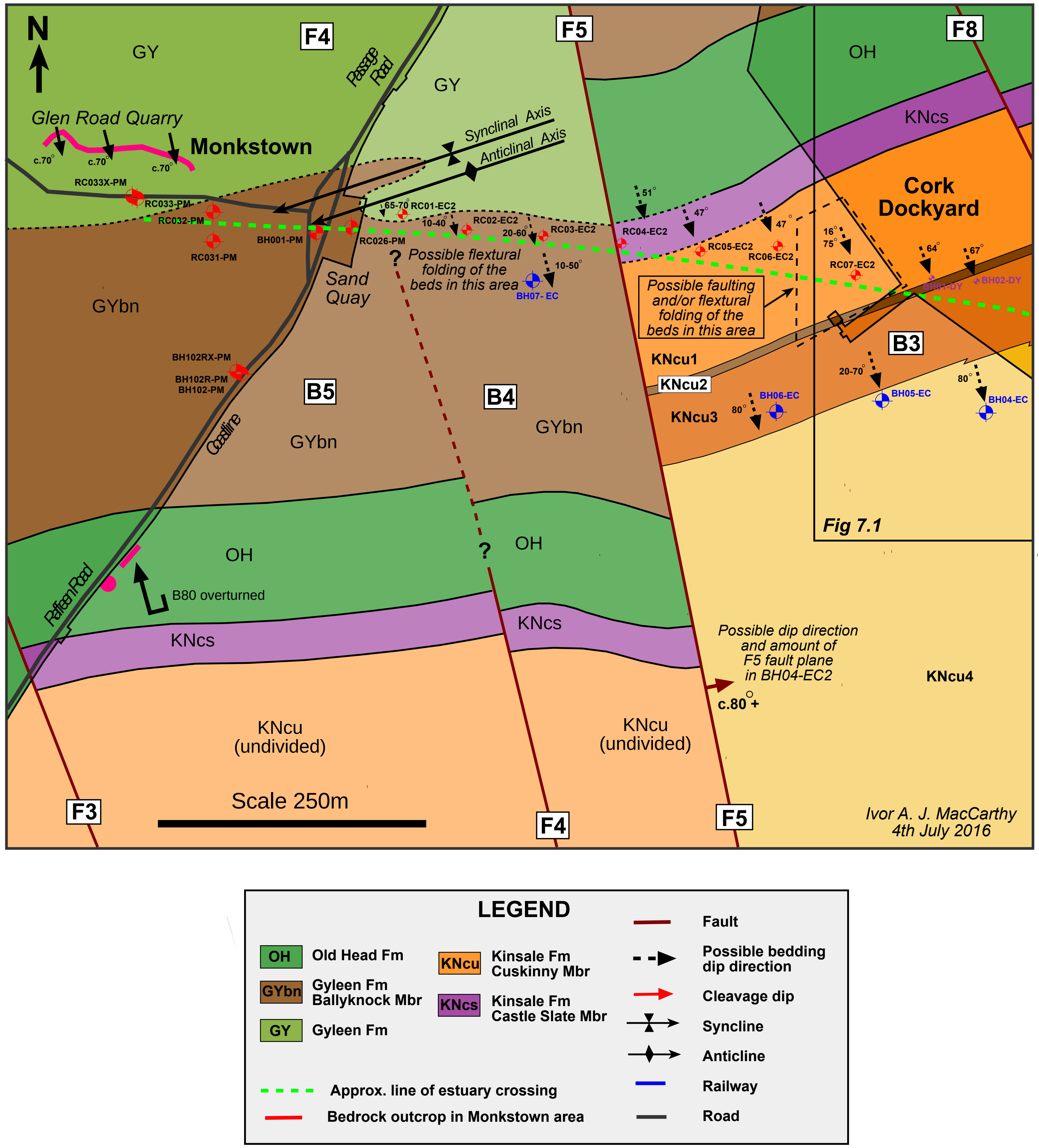


Fig 13.1b. Detailed map of the bedrock geology of the Cobh-Monkstown estuary crossing area (Model 2).

Fig 13.2. Ballytrasna Formation Passage Road, Monkstown showing selected intersecting bedding planes (green lines), joint planes (JP and purple lines) and cleavage planes (red) in purple/red fine-grained sandstones and siltstones. The strike of the joints intersects the strike of the bedding and cleavage at very high angles. The same rock face is shown in both images but viewed from a different angle. JP1 is the same joint plane in both images.

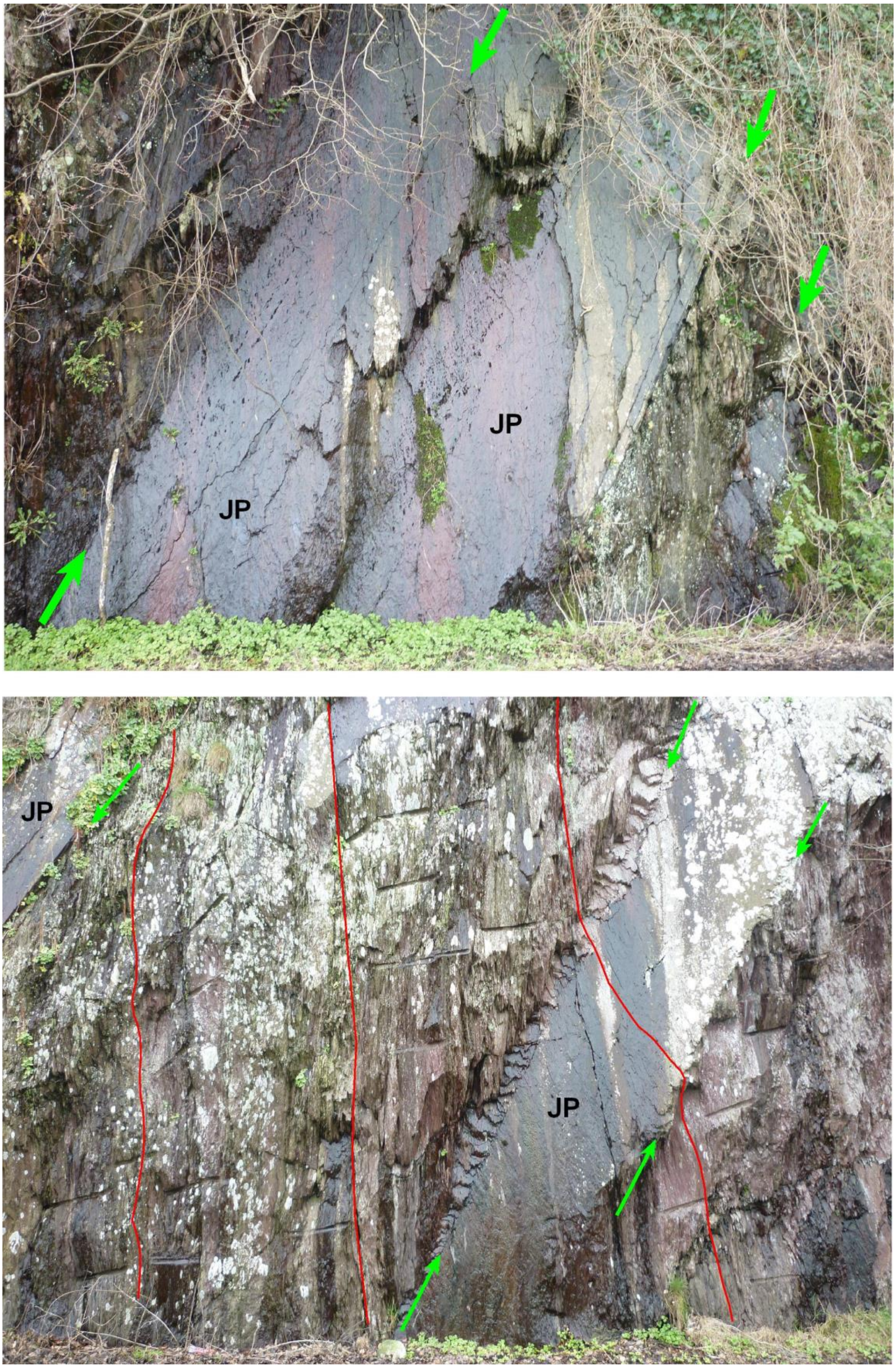


Fig 13.3. Ballytrasna Formation in Monkstown showing strongly cleaved siltstones alternating with finer-grained sandstones. Note refracted ENE-WSW striking cleavage planes (red lines) intersecting prominent NNW-SSE striking joint planes (JP). Green arrows-Bedding planes.

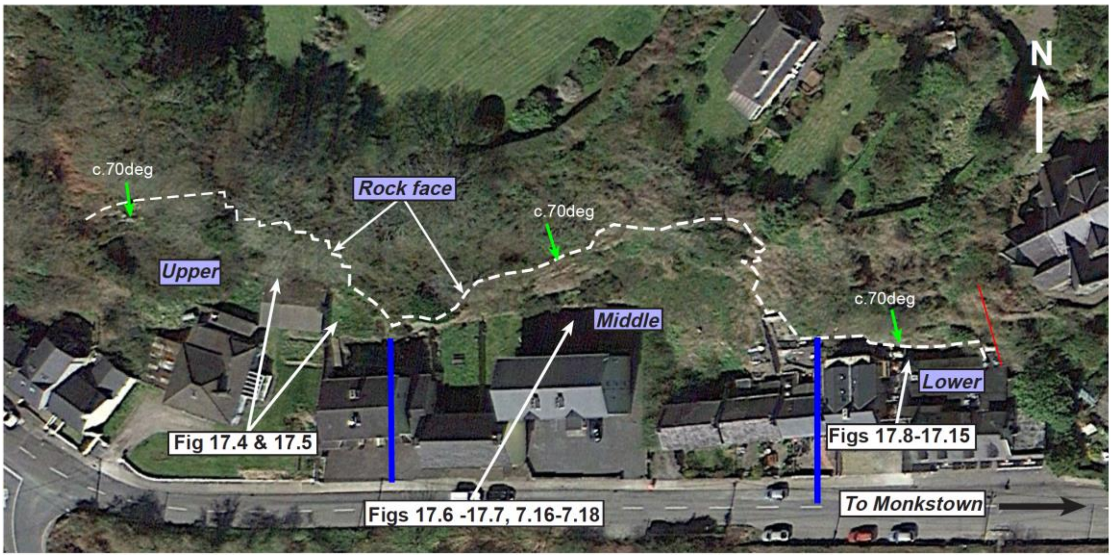


Fig 13.4. Aerial image of Glen Road Quarry, Monkstown. Top of rock face is the white dash line. Green symbols show dip direction of bedding planes. Red line shows general strike of steeply inclined dominant joints across the site.
(Image *Google Earth*)

Fig 13.5. Jointing in Facies 1 pale green sandstones and siltstones of the Gyleen Formation at Glen Road Quarry (upper).
Arrows-Joints, Green line-bedding, Red line-cleavage.

Fig 13.6. Jointing, bedding and cleavage in Facies 1 pale green sandstones and siltstones of the Gyleen Formation at Glen Road Quarry (upper).
J-Joints, Green line-bedding, Red line-cleavage, Purple line-Fault.

Fig 13.7. Steeply dipping bedding planes in the Gyleen Formation at Glen Road Quarry (middle).
Green lines-Bedding.
mSt-Facies 1-Medium-grained pale green sandstones.
PfSt/Slt-Facies 2-Purple fine-grained sandstone and siltstone.
BP-Bedding plane, JP-Joint plane.

Fig 13.8. Steeply dipping bedding planes in the Gyleen Formation at Glen Road Quarry (middle). Facies 2-Bedded purple fine-grained sandstones and siltstones. Note vertical fracture at top of image that appears to be part of a bedding-parallel thrust fault associated with layer-parallel shortening that took place at the initial stages of deformation. The fracture commenced parallel to lower level bedding planes and then cut upwards across the bedding.

Fig 13.9. Gyleen Formation at Glen Road Quarry (lower) showing steeply inclined jointing in Facies 2-Well-bedded alternating purple sandstones and mudstones. The planes inclined towards the viewer are bedding planes.

Fig 13.10. Gyleen Formation at Glen Road Quarry (lower). The surface in the centre is a joint plane. The pale coloured surface on the left side is a bedding plane. Facies 2- Well-bedded alternating purple sandstones and mudstones.
Bedding planes dip steeply to the right (southwards).

Fig 13.11. Gyleen Formation Glen Road Quarry (lower) showing fracture patterns in Facies 2-Well-bedded alternating purple sandstones and mudstones. Planes inclined towards the viewer are bedding planes.

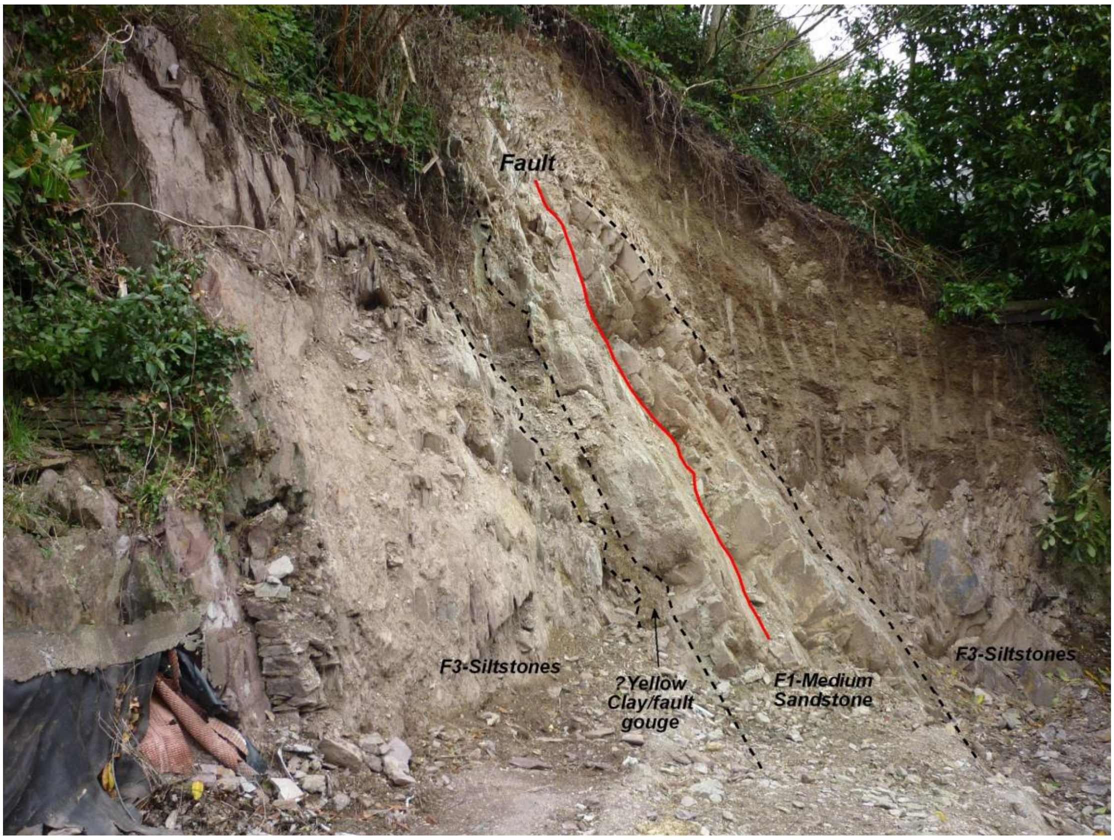


Fig 13.12. Gyleen Formation Glen Road Quarry (lower). F1-Facies 1-Pale green medium-grained sandstones. F3-Pale purple siltstones with partial green secondary colouration derived from overlying sandstones. Note thrust fault (red line) in sandstone unit.

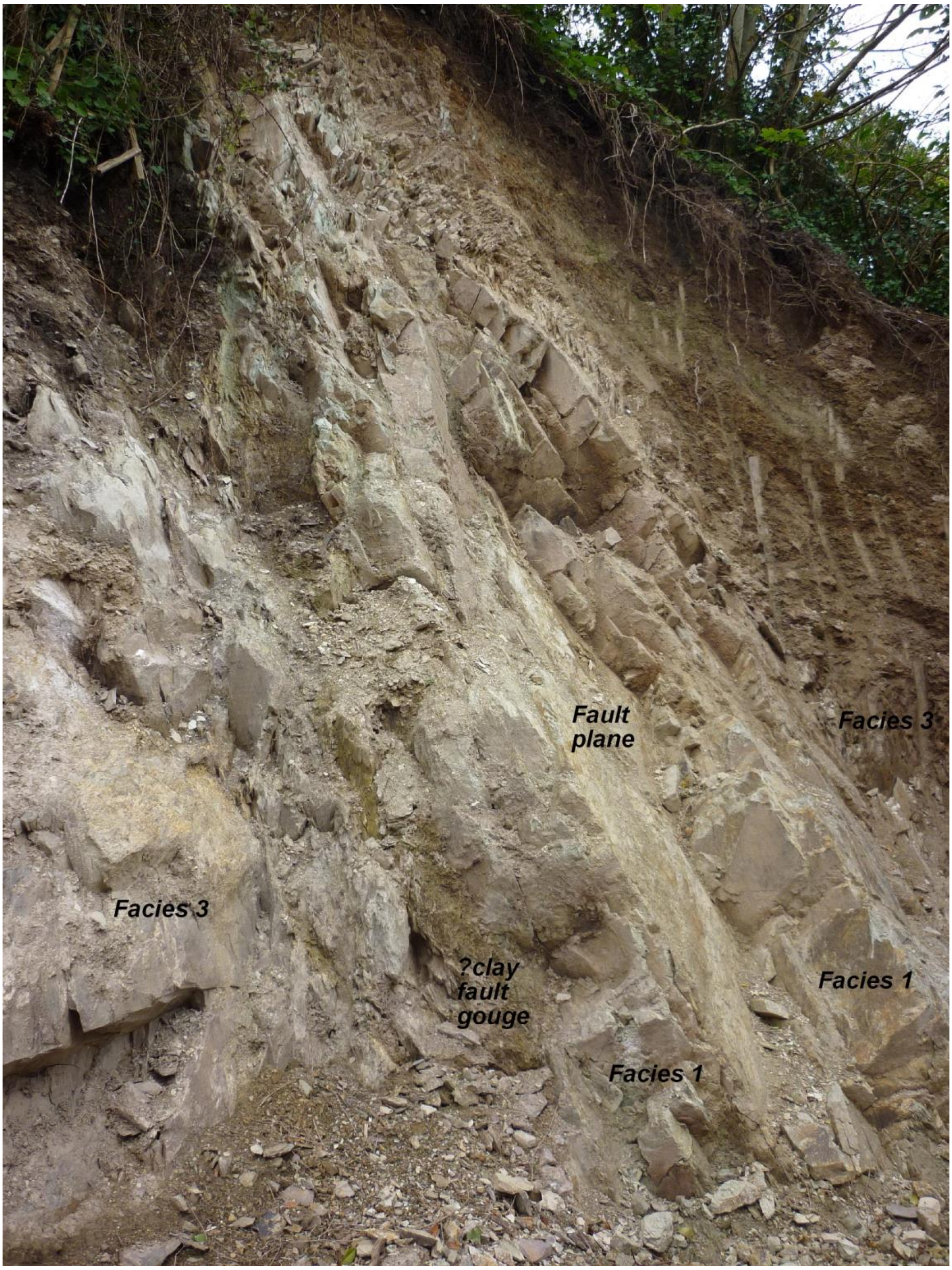


Fig 13.13. Gyleen Formation Glen Road Quarry (lower) showing close-up view of Fig 13.12.

Fig 13.14. Gyleen Formation Glen Road Quarry (lower) showing close-up of Fig 13.12.

Fig 13.15. Gyleen Formation Glen Road Quarry (lower) showing intersection of joints on bedding plane in Facies 1 sandstones as shown in Fig 13.13. The bedding plane is inclined towards the viewer. The pale coloured plane on the left is a fault plane.

Fig 13.16. Gyleen Formation Glen Road Quarry (lower) showing Facies 3-Purple mudstones with strong sub-vertical cleavage fabric. Bedding planes are inclined to the right at about 45°.

Fig 13.17. Example of the style of jointing (red lines) in the Gyleen Formation at The Haggart, Glen Road Quarry (middle), Monkstown.

Fig 13.18. Detail of part of Fig. 13.17 showing intense jointing in the Gyleen Formation Glen Road Quarry (middle), Monkstown.

Fig 13.19. Jointing in the Gyleen Formation, The Haggart, Glen Road Quarry (middle), Monkstown. Q-Quartz filled joints.

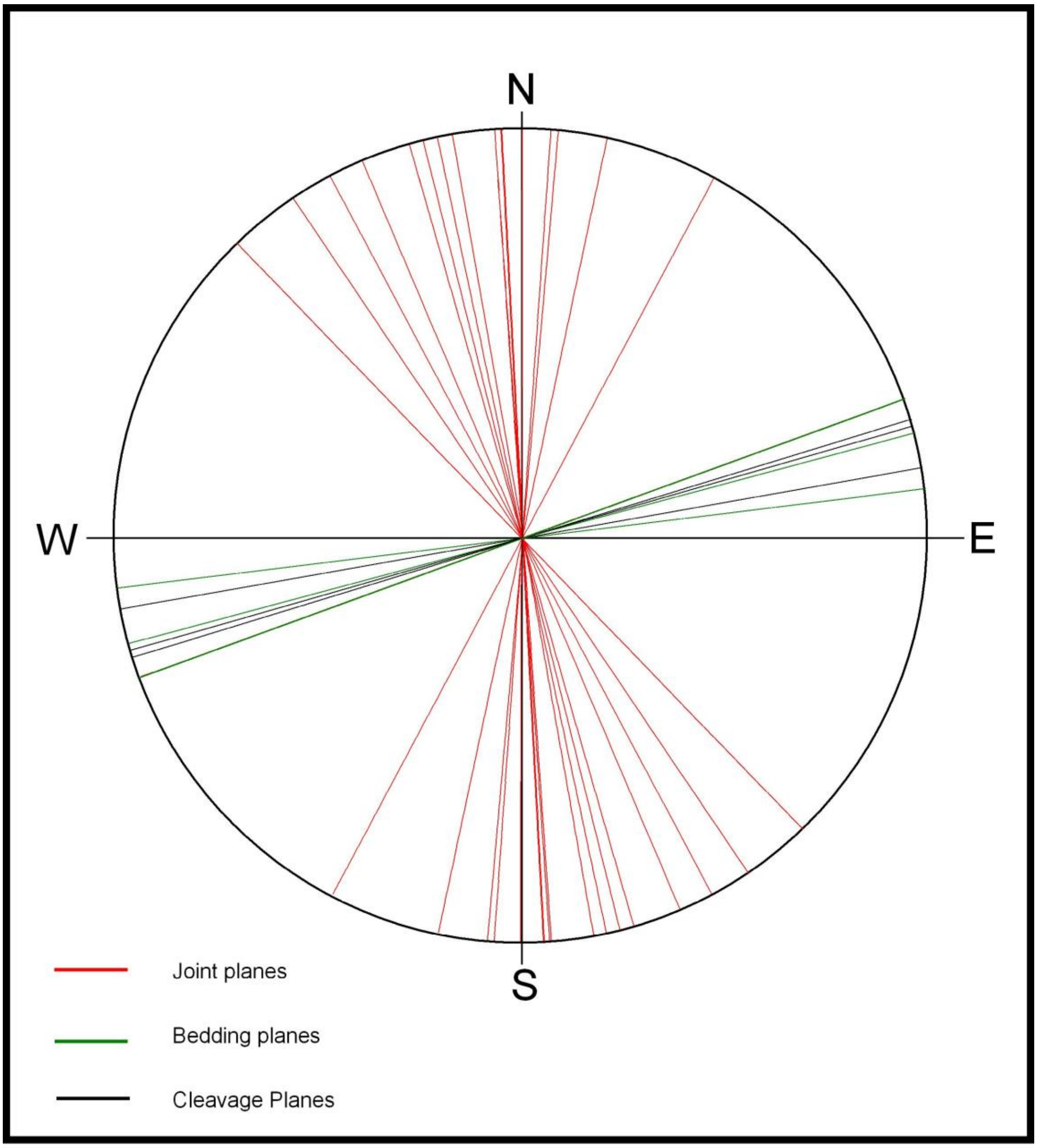


Fig 13.20. Strike orientations of discontinuities in the bedrock (Ballytrasna and Gyleen Formations) at Monkstown.

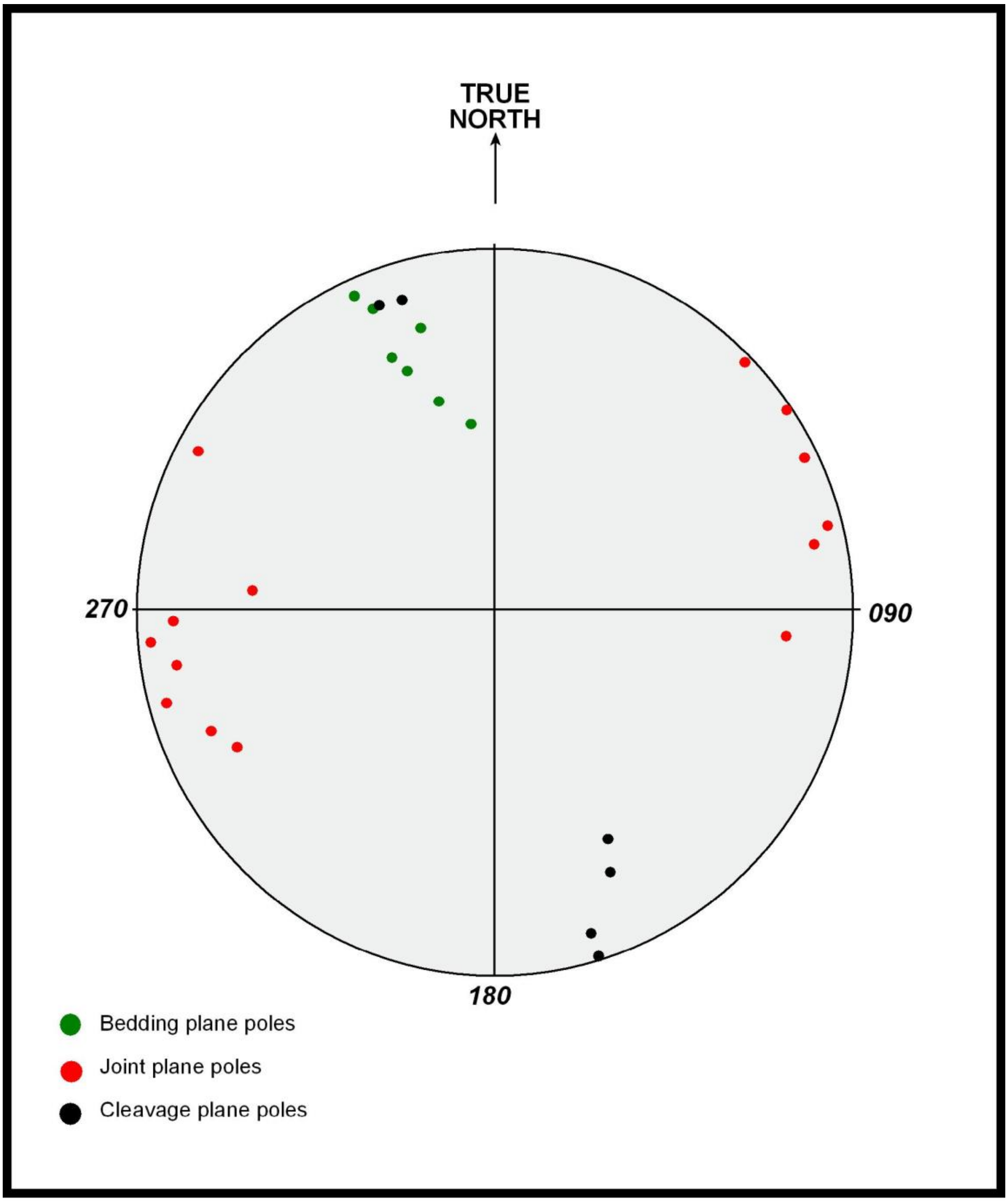


Fig 13.21. Stereographical projections of poles of representative bedding, joint and cleavage planes in the bedrock (Ballytrasna and Gyleen Formations) at Monkstown.

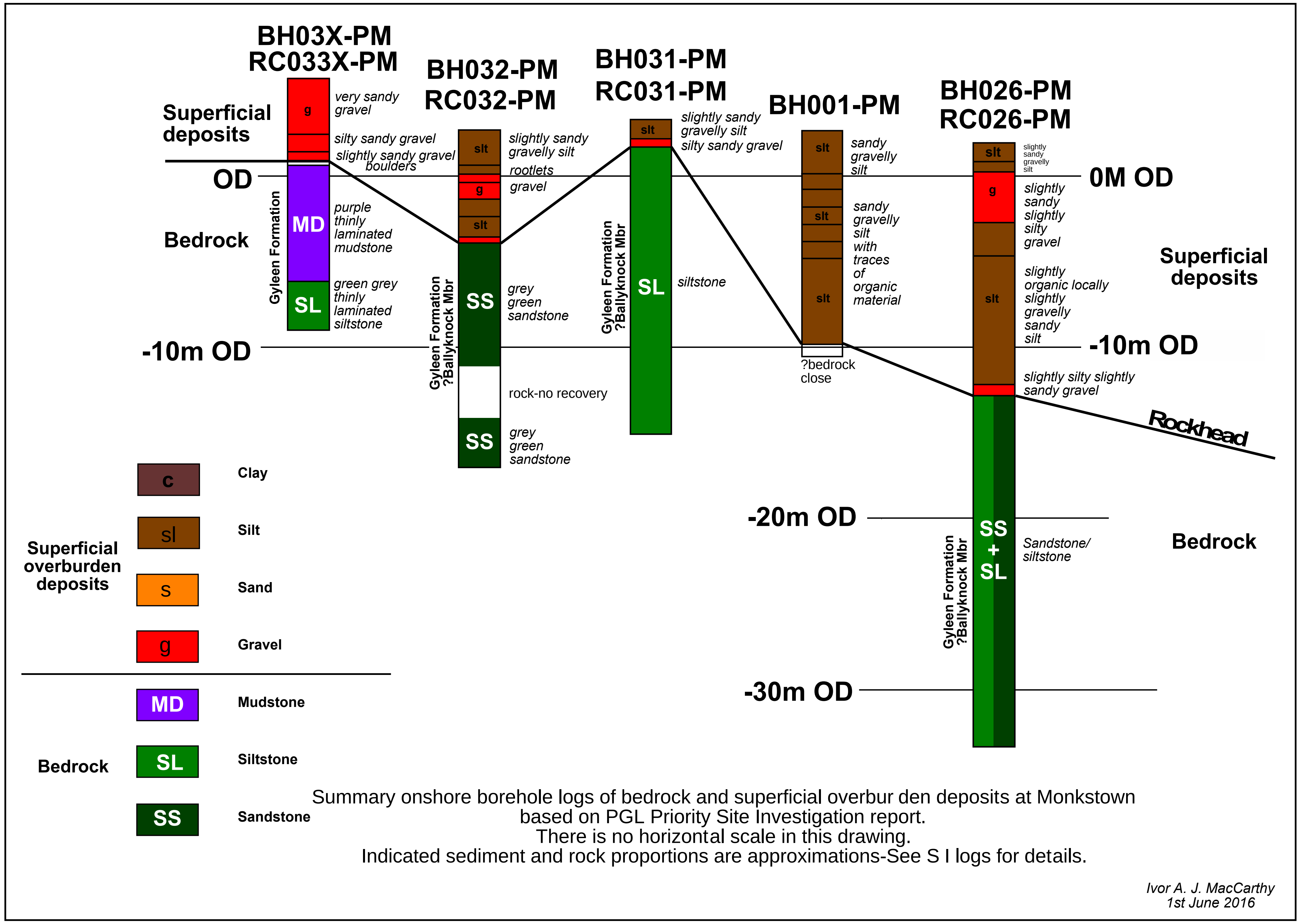


Fig 13.22. Summary onshore PM borehole logs at Monkstown.

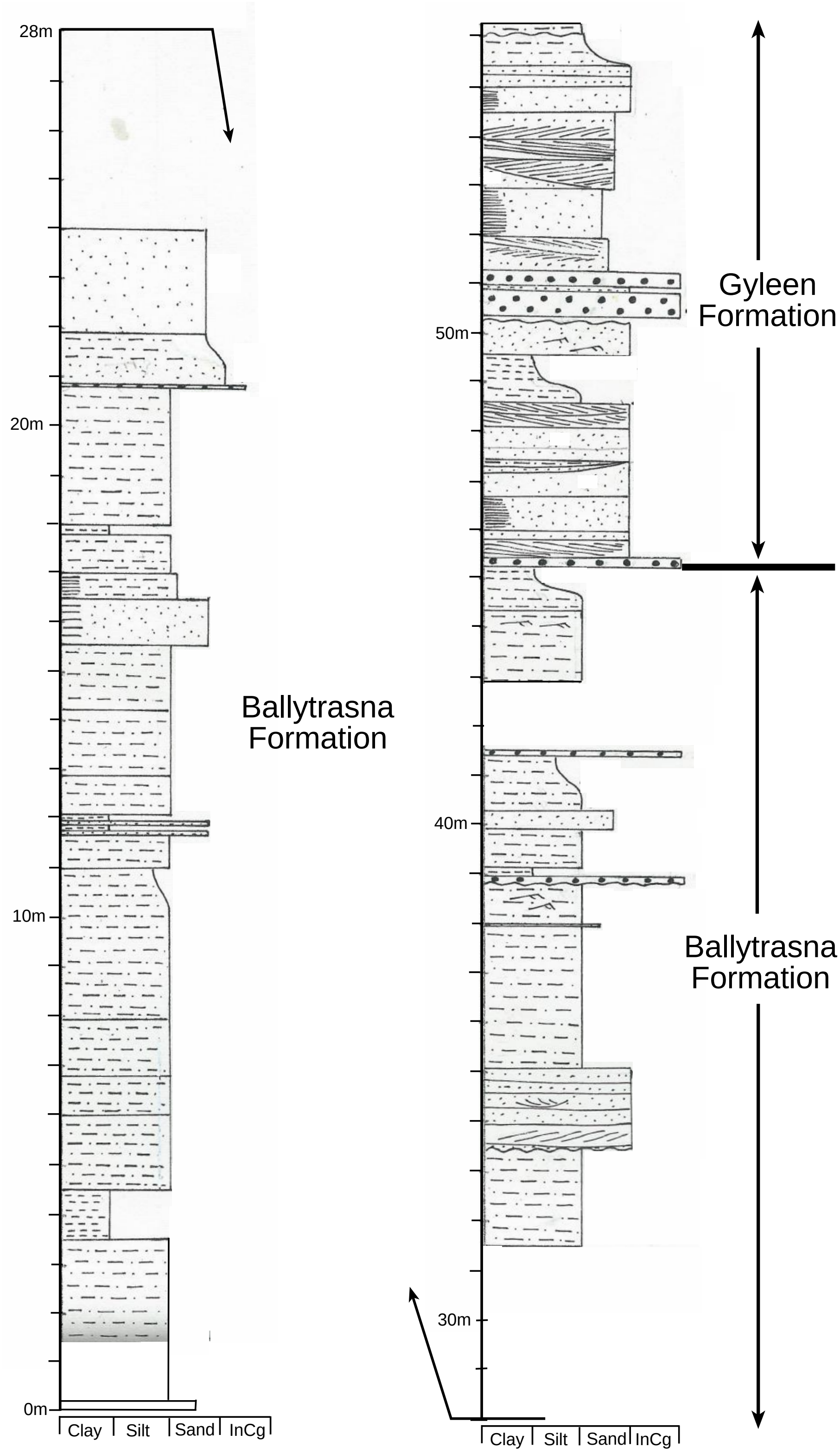


Fig 13.23. Detailed stratigraphical log of the Ballytrasna Formation and its transition into the lower part of the Gyleen Formation at Passage Road roadside outcrop. The intraformational conglomerates are partially calcareous.

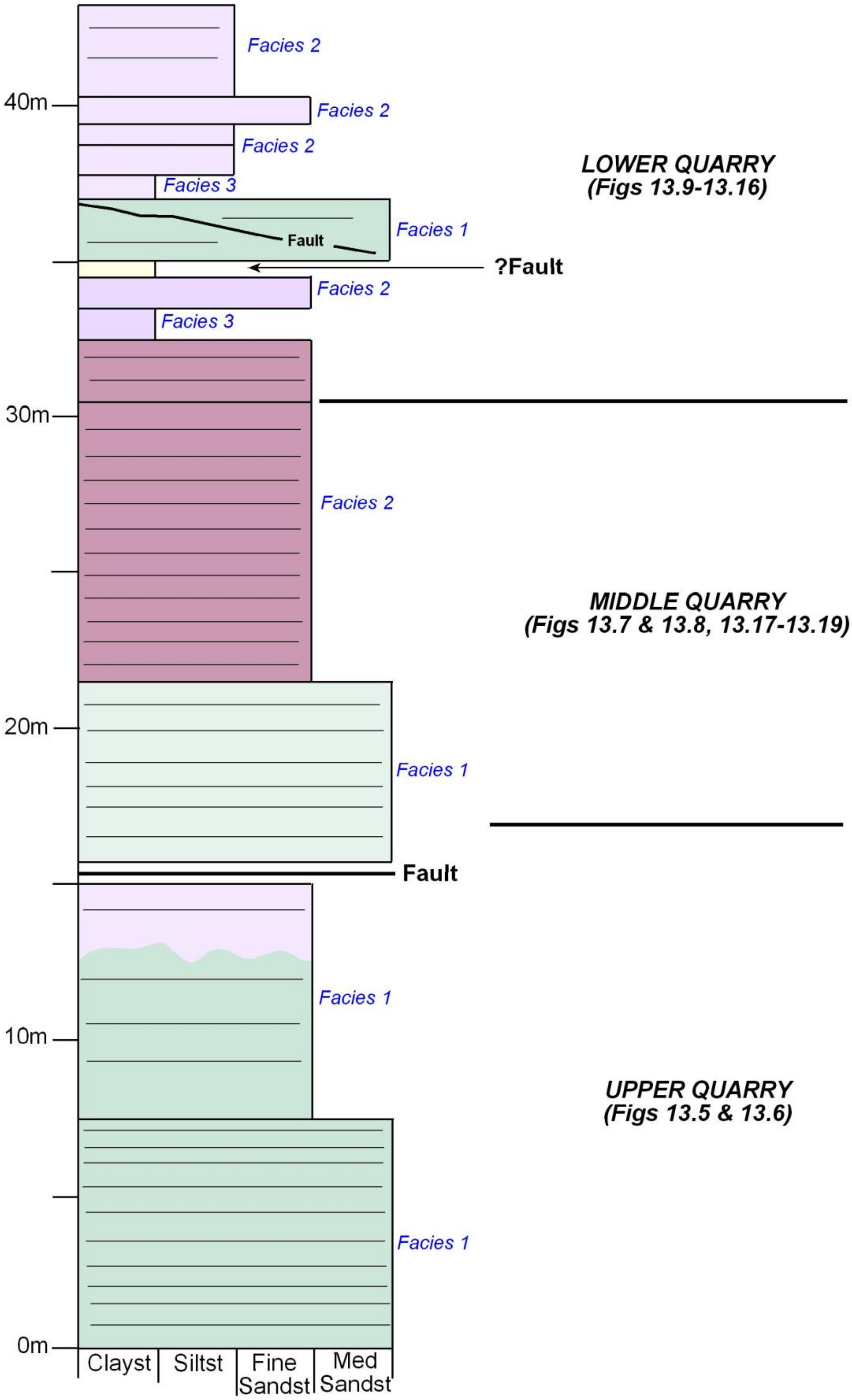
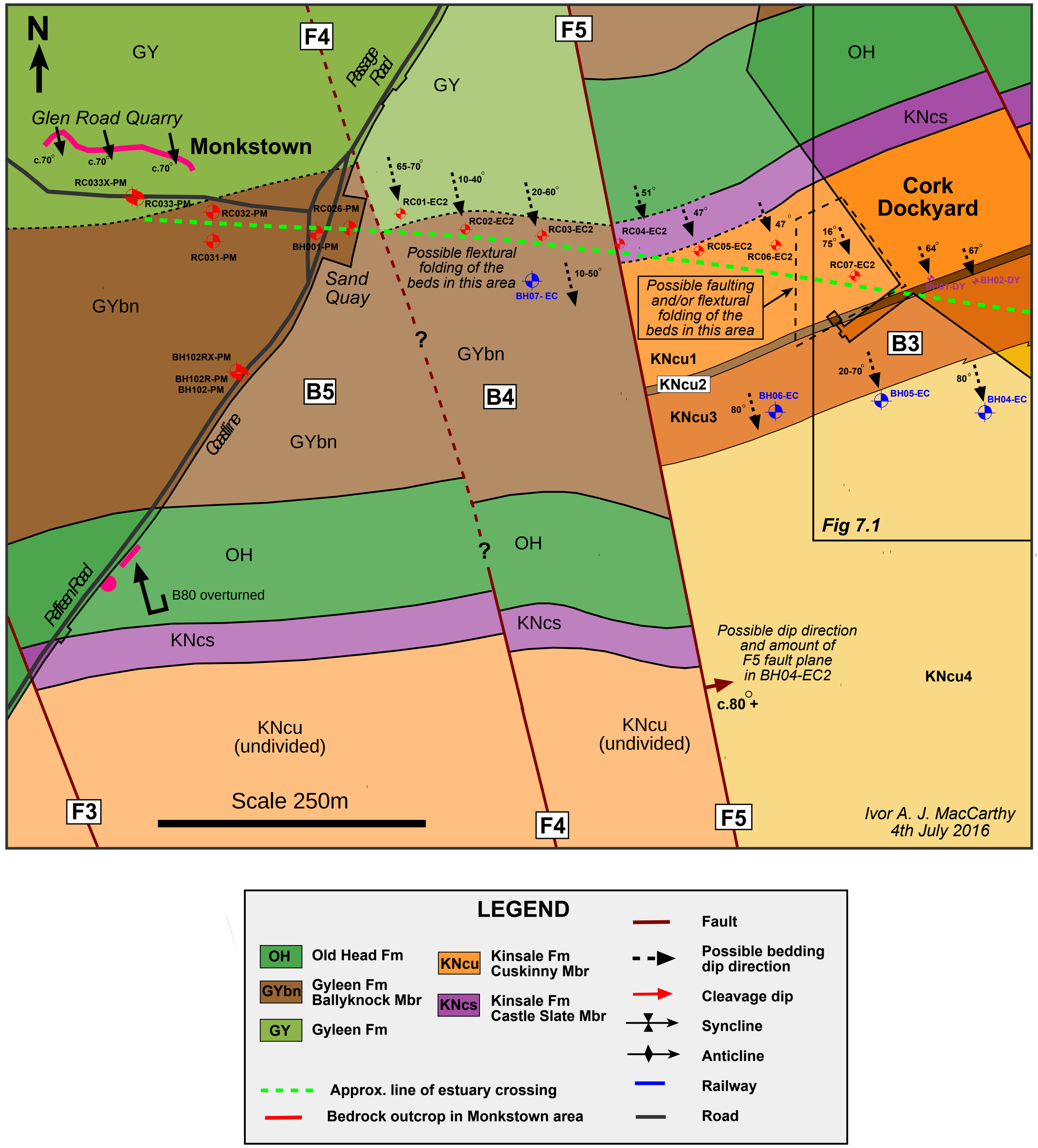


Fig 13.24. Schematic stratigraphical log of the upper part of the Gyleen Formation at Glen Road Quarry.



(Fig 13.1a Duplicate). Detailed map of the bedrock geology of the Cobh-Monkstown estuary crossing area and the Monkstown onshore area. **NOTE**: The directions of bedding dip in the offshore and Cork Dockyard areas are speculative. They are based on the regional structural trend. Deviations from these are highly possible and to be expected. See detailed stratigraphical legend in Page 70.

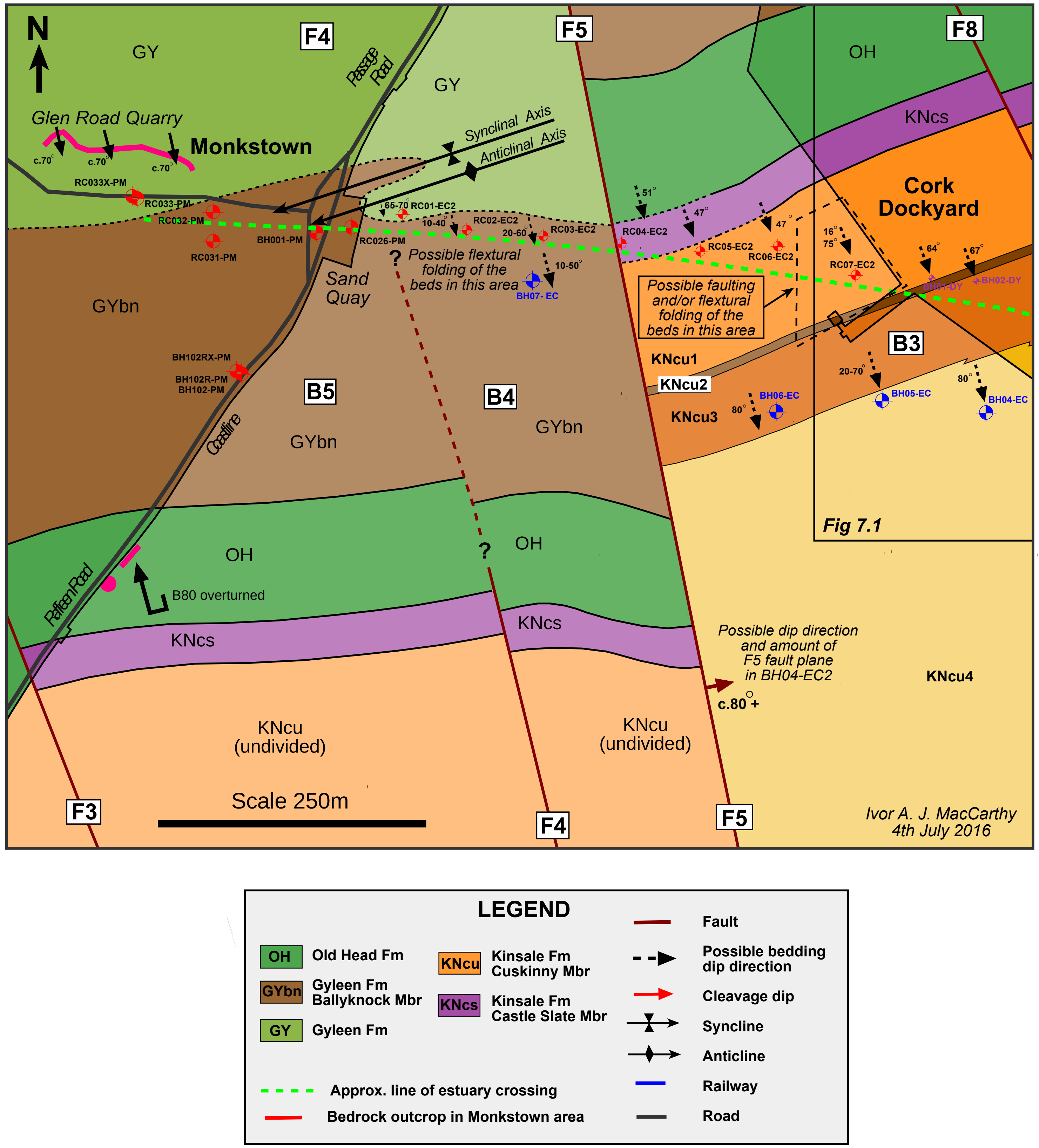


Fig 13.1b. Detailed map of the bedrock geology of the Cobh-Monkstown estuary crossing area (Model 2).

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	**RC01-EC2**	**DEPTH -mOD**	**BOX THICKNESS cm**	**FINE STN**	**MED STN**	**COARSE STN**	**SILTSTONE**	**WEATHERED/BROKEN/GAPS/NI**	**BEDDING**	**CLEAVAGE**	**JOINTS**	**WEATHERING**	**NOTES**
2	**BOX 1**	-15.2 to -18.55	330		123			207	70°		85°	W1/W2	16 red mst, 4 g-brown (W4) mst, 103 grey green mst/
3	**BOX 2**	-18.55 to -21.5	300	47	63		130	60				W1/W2/W3	63 green grey mst (W3), 40 green grey slt, 47 green fst, 90 red (5R6-2) slt
4	**BOX 3**	-21.5 to -24.5	300				100	200					red slt (5R6-2)/ top 55cm strongly weathered
5	**BOX 4**	-24.5 to -27.15	265		60		185	20					red (5R6-2) slt
6	**BOX 5**	-27.15 to -30.25	310	60	37		100	113	50, 70°				red slt, red fst (5R5-2), green st/
7	**BOX 6**	-30.25 to -33.15	290	170	35		85		70°	80°			red (5R6-2) and green slts and sands
8	**BOX 7**	-33.15 to -35.65	250	239				11	60°			W1/W2/W3	light bluish grey (5B8-1) fst
9	**BOX 8**	-35.65 to -38.4	275	58	208			9	70°		45, 55°		greenish grey (5G6-1, 5G7-1) st/alternatons of coarse and fine laminae
10	**BOX 9**	-38.4 to -42.2	380		220			160	65°				yellowish grey (5Y 7-2), light bluish grey (5B 7-1)/6qtz veins dip 55°
11	**BOX 10**	-42.2 to -44.95	275		200			75	65°				yellowish grey (5Y 6-2), light bluish grey (5B 7-1)/upper brown uint extensive thick qyz veins 3, 5, 6, 15, 50mm wide
12	**BOX 11**	-44.95 to -47.7	275		215			60	80-85°				60 pale blue mst, 155 brown weathered mst/network of qtz veins throughout
13	**BOX 12**	-47.7 to -50.0m	230		40			190				W3	?mst here
14													
15													
16	**TOTALS cm**		3480	574	1201		600	1105	Av. 75°				
17	**TOTALS %**			16.49	34.51		17.24	31.75					**CONCLUSIONS: The lithological composition of this core suggests that it is the Ballyknock Member (Gyleen Formation)**
18													
19													
20													
21	**RC02-EC2**	**DEPTH -mOD**	**BOX THICKNESS cm**	**FINE STN**	**MED STN**	**COARSE STN**	**SILTSTONE**	**WEATHERED/BROKEN/GAPS/NI**	**BEDDING**	**CLEAVAGE**	**JOINTS**	**WEATHERING**	**NOTES**
22	**BOX 1**	-16.8 to -18.9	210	20	136		20	34	30°		30°, 58°, qtz vein	W1/W2/W4	greenish gy st 5GY5-1/9 thin discontinuous parallel qtz veins dip 20, 65-75° in same direction, en echelon/iron staining
23	**BOX 2**	-18.9 to -20.8	190		165			25	60°		40, 50, 70°	W1/W2	greenish gy st/network of c.26 thin qtz veins/various orientations 0-90°
24	**BOX 3**	-20.8 to -22.9	210		148			62	30-40°			W1/W2	greenish gy st/intense fracturing/network of c.6 thin qtz veins c.10-85°/extensive iron staining in NI zones
25	**BOX 4**	-22.9 to -24.9	200	26	129		4	41	10-20°		60, 75°	W1/W2	greenish gy st/joints iron stained/minor qtz veins at one level
26	**BOX 5**	-24.9 to -26.85	195		184			11	c.10°		10, 20, 70-80	W1/W2	greenish gy st 5G7-1/qtz veins/iron staining on joints, bedding plane, quartz veins and NI zones
27	**BOX 6**	-26.85 to -28.9	205	132	20			53	c.10-15°		80°	W!/W2/W3	light to medium light greenish grey (5G7-1) fine-med st/20cm of med sandstone heavily weathered W3
28	**BOX 7**	-28.9 to -30.85	195	155	40				c.30°		65°	W!/W2	Greenish grey (5G7-1) st/iron staining on most discontinuities and fractures
29	**BOX 8**	-30.85 to -32.85	200	65			90	45	25°		80-90°	W!/W2	light to medium greenish (5B7-1) grey fine and med st/iron staining on some NI pieces
30	**BOX 9**	-32.85 to -34.6	175		150		25				50, 80°	W1/W2	light to medium greenish grey (5G7-1) fine and med st/iron staining on some NI pieces
31	**BOX 10**	-34.6 to -36.6	200	72	93			35	?25°		2 sets intersecting	W1/W2	light greenish grey to light bluish grey st/11 joints/c.8 thin qtz veins infilling joints/iron staining on most discontinuities and fractures
32	**BOX 11**	-36.6 to -38.35	178	60	55		5	58	25°		50 80°	W1/W2/W3	light greenish grey (5GY6-1) lam st & slt/1 qtz vein/iron staining on one bedding, most discontinuities and fractures/W3 local on one bedding/soft sed deformation
33	**BOX 12**	-38.35 to -40.35	200		125	53	22		20°		70°	W1/W2/W3	light to medium bluish grey st/4 qtz veins/ 45cm orange weathered bed locally W3 weathering
34	**BOX 13**	-40.35 to -42.25	190	160	10		20		35°		45, 85°	W1/W2	light greenish grey ?fine grained st-slt
35	**BOX 14**	-42.25 to -44.2	195	43	152				35°		75, 80-85°	W1/W2	light greenish grey, ?light greyish blue to pale purple st/intense iron staining on one bedding, most discontinuities and fractures/orange on one bedding contact
36	**BOX 15**	-44.2 to -46.1	190		190				?35°		70, 80-85°	W1/W2	light greenish grey (5G7-1) fine to med st/8 qtz veins infilling joints/intense iron staining along joints
37	**BOX 16**	-46.1 to -48.05	195		160	35			20°		30, 45, 70°	W1/W2/W3	light to medium bluish grey med sts/greenish-yellowish grey (5GY6/1) coarse st/coarse st strongly weathered W3/intense iron staining along joints
38	**BOX 17**	-48.05 to -50.1	205	155			50		25°		70°	W1/W2	greenish grey (N6) med st/palered (5R5-2) fine st
39	**BOX 18**	to -50.5	40				40					W1/W2	red (5R5-2) slt with discolouration/ broken
40													
41													**NOTES: The presence of intense quartz veining is commmonly associated with sandstones.**
42													**May also indicate the presence of faulting and/or tight folding in sandstones**
43	**TOTALS cm**		3373	888	1757	88	276	364	Av. 27°				***Values for all lithologies and NI in cm.**
44	**TOTALS %**			26.33	52.09	2.61	8.18	10.79					**CONCLUSIONS: This core is typical of the lower part of the Ballyknock Member of the Gyleen Formation**
45													
46													
47													
48	**BH03-EC2**	**DEPTH mOD**	**BOX THICKNESS cm**	**FINE STN**	**MED STN**	**COARSE STN**	**SILTSTONE**	**WEATHERED/BROKEN/GAPS/NI**	**BEDDING**	**CLEAVAGE**	**JOINTS**	**WEATHERING**	**NOTES**
49	**BOX 1**	-26.7 to - 29.5	280		148		115	17		65°		W1/W2	green grey(5GY7-1) m st, g lt/ brecciated qtz veins at top ?fault zone
50	**BOX 2**	-29.5 to - 32.3	280	35			239	6			75-85°	W1/W2	greenish gy (5G6-1) st and slt/3 qtz veins/iron weathering on joints
51	**BOX 3**	-32.3 to - 34.95	265		10		210	45	45°	40-55°		W1/W2	greenish bluish gy (N5-5B6-1) st and slt
52	**BOX 4**	-34.95 to -37.6	265		100		165		40°		85-90°	W1/W2	grey (N5-N6) st and slt
53	**BOX 5**	-37.6 to -40.35	275	126	119	30			60°	80°+		W1/W2	gy (N5-N6) fst and mst/30 coarse is an intraformational conglomerate/fst is laminated
54	**BOX 6**	-40.35 to -43.35	300	54	25	55	96	70	35°		75°	W1/W2	grey green/thin coarse and fine alternations common
55	**BOX 7**	-43.35 to -46.05	270	263		7						W1/W2	grenish grey (5G7-1) fst, slt
56	**BOX 8**	-46.05 to -48.85	280	131	117			32			60°	W1/W2	grey green/ 43 of fst is brown W3
57	**BOX 9**	-48.85 to -51.55	270	200	70				45°	55°		W1/W2	grey green/qtz veins up to 50mm, mostly <8mm
58	**BOX 10**	-51.55 to -54.4	285	66	101	20		98				W1/W2	light greenish grey (5G7-1)
59	**BOX 11**	-54.4 to -57.1	270	95	30		145		20°		80°	W1/W2	green grey (5G7-1) mst at top, red brown (5R5-2) fst with calcrete blobs, green fst calcretised grading down to brown slt, red brown slt
60	**BOX 12**	-57.1 to - 60.0	290	245			45					W1/W2	red brown and green fst, brown slt
61													
62													**CONCLUSIONS: This core is typical of the lower part of the Ballyknock Member of the Gyleen Formation**
63	**TOTALS cm**		3330	1215	720	112	1015	268	Av. 41°				
64	**TOTALS %**			36.49	21.62	3.36	30.48	8.04					**ABBREVIATIONS**
65													md-mudstone (siltstone/claystone/slt-siltstone), cl-claystone, slt-siltstone, fst-fine-grained sandstone, mst-medium-grained sandstone.

Fig 14.1. Summary of bedrock geological characteristics of RC01-EC2 to RC03-EC2.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	**BH04-EC2**	**DEPTH mOD**	**BOX THICKNESS cm**	**FINE STN**	**MED STN**	**FLASER**	**SILTSTONE**	**CLAYSTONE**	**BRECCIATED ST/SLT**	**WFG**	**BEDDING**	**CLEAVAGE**	**JOINTS**	**WEATHERING**	**NOTES**
2	**BOX 1**	-30 to -34.75	not bedrock												mostly rounded pebbles, cobbles and boulders composed of red and green sts/probably superficial deposits above bedrock/ **CASTLE SLATE MEMBER**
3	**BOX 2**	-34.75 to -39.75	500					60	180	260				W3/W4/W5	dark grey claystone (N3-N4), mostly degraded insitu to soil-like form with relict insitu bedrock preserved in places / **CASTLE SLATE MEMBER**
4	**BOX 3**	-39.75 to -43.5	375			60		130	94	91	80°			W3/W4/W5	dark grey claystone (N3-N4), mostly degraded insitu to soil-like form with relict insitu bedrock preserved in places/minor flaser bedding 60-90% st, 10-40% claystone/**CASTLE SLATE MEMBER**
5	**BOX 4**	-43.5 to -46.15	265		26			125	92	22	45°	40°		W2/W4	dark grey (N6 to N7) claystone and green st strongly brecciated and fractured/greenish grey clasts in a N7 fine matrix/5cm qtz vein at contact zone, qtz veins in underlying st/ **KNcs in fault contact with GYbn**
6	**BOX 5**	-46.15 to -49.1	295	110					170	15	65°			W1/W2	pale greenish grey (5G7-1) laminated fst-slt (N6-N7) alternations/insitu brecciation due to faulting/**BALLYKNOCK MEMBER**
7	**BOX 6**	-49.1 to -52.45	335	30			222		34	49	50°			W1/W2	pale greenish grey (5G5-1) laminated slts and thin fine st layers/repid alternations of coarse and fine/vertical cleavage contributing to fracturing and poor rock quality/**BALLYKNOCK MEMBER**
8	**BOX 7**	-52.45 to -55.1	265	23			242				40°	70-90°	75°	W1/W2	1mm qtz veins infill cleavage, 4 veins fll joints at 40°/pale green lam fst fining down to greyish red (5R4-2 to 5R6-2) slt/colour penetrates down along cleavage post deformation/ sparse calcrete nodules
9	**BOX 8**	-55.1 to - 57.75	265	119			146				35-40°		65, 85°	W1/W2	red slt with thin fst streaks grading down to pale green bluish grey (5B6-1) fsts and slts/extensive network of vertical fractures possibly associated with cleavage/**BALLYKNOCK MEMBER**
10	**BOX 9**	-57.75 to -60.15	240		210		30				40°		75, 80°	W1/W2	pale greenish grey fine st (N6-N7/5G7-1) and slt (5G7-1) alternating rapidly, gy green med st/6 qtz veins/**BALLYKNOCK MEMBER**
11															
12															
13	**TOTALS cm**		2540	282	236	60	640	315	570	437	Av. 51°				**CONCLUSIONS**
14	**TOTALS %**			11.1	9.29	2.36	25.2	12.4	22.44	17.2					Boxes 1 and 2 are KNcs, Box 3 contains KNcs above in faulted contact with Gybn below. The brecciated levels define the shatter zone of the fault.
15															
16															**ABBREVIATIONS**
17															md-mudstone (siltstone/claystone/slt-siltstone), cl-claystone, slt-siltstone, fst-fine-grained sandstone, mst-medium-grained sandstone.
18															WFG-Weathered fault gouge

Fig 14.2. Summary of bedrock geological characteristics of RC04-EC2.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	**BH05-EC2**	**DEPTH mOD**	**BOX THICKNESS cm**	**FINE STN**	**MED STN**	**SILTSTONE**	**CLAYSTONE**	**FLASER**	**LINSEN**	**GAPS/BROKEN/WEATHERED/NI**	**BEDDING**	**CLEAVAGE**	**JOINTS**	**WEATHERING**	**NOTES**
2	**BOX 1**	-27.0 to -37.2	1020			80		20		920	45°		70°	W1-W2	gy (N5) slt/flaser 90% st/thin qtz veins/upper 120cm broken ?partially bedrock
3	**BOX 2**	-37.2 to -39.85	265		60			175		30	40°		65°	W1-W2	gy (N3-N4), flaser 80-90%st
4	**BOX 3**	-39.85 to -42.95	310	110			40	15		145	50°		80°	W1-W2	gy (N4-N5)
5	**BOX 4**	-42.95 to -45.3	235				200		35		48°		70°	W1-W2	veins 48° /(N3-N4)/claystones silty/linsen 20-30%st
6	**BOX 5**	-45.3 to -48.1	280	10			37	95	110	28	55°		50, 80°	W1-W2	linsen 10-30%st/ gy (N3)/flaser 50-100%st/flaser strongly burrowed
7	**BOX 6**	-48.1 to -50.6	250	210	40						55°		30, 50, 70°	W1-W2	29 qtz veins 1-3mm/sts intensely burrowed wit md streaks common (N2-N3)
8	**BOX7**	-50.6 to -53.45	285	195			35	20	35		45°		50°	W1-W2	flaser 70-90st (N5-N6)/linsen 10-20%st (N2-N3)/several fsts very dark (N2-N3)md streaks and burrowed
9	**BOX 8**	-53.45 to -56.0	255					255			45°		50°	W1-W2	36 qtz veins/flaser 95% gy st/local burrowing/thin mmscale clay and silt laminae
10	**BOX 9**	56.0 to -58.75	275					170		105	45°			W1-W2	gy (N4-N6) flaser 85-95%st/18cm and 15cm thick quartz filled brecciated levels-?faulting/very fractured box
11	**BOX 10**	-58.75 to -60.55	180					110		70	45°			W1-W2	gy (N3-N4) flaser 80%st/thin subvertical veins
12															
13	**TOTALS cm**		3355	525	100	80	312	860	180	1298	Av. 47°				**CONCLUSION: This core is probably from the Cuskinny Member**
14	**TOTALS %**			15.65	2.98	2.39	9.3	25.63	5.37	38.69					
15															
16	**BH06-EC2**	**DEPTH mOD**	**BOX THICKNESS cm**	**FINE STN**	**MED STN**	**SILTSTONE**	**CLAYSTONE**	**FLASER**	**LINSEN**	**GAPS/BROKEN/WEATHERED/NI**	**BEDDING**	**CLEAVAGE**	**JOINTS**	**WEATHERING**	**NOTES**
17	**BOX 1**	-19.35 to -21.55	220		107					113	45°			W1-W2	greenish grey (5GY6-1) mst, Box a-broken bedrock of greenish grey mst
18	**BOX 2**	-21.55 to -24.6	305		203		20			82	45°			W1-W2	greenish grey laminated mst, weathered brown/ grey (N3) claystone/ ?fault cross-cuts core 38cm of very broken material/clay weathered brown
19	**BOX 3**	-24.6 to -27.95	335		103		23		129	80	50°		30, 60, 75, 90°	W1-W2	greenish grey mst/clay grey (N4)/qtz veins infilling joints/linsen slt 25-40%st, grey (N3-3)
20	**BOX 4**	-27.95 to -30.8	285						257	28	40°			W1-W3	linsen slt 20-30%st grey (N3-N4)
21	**BOX 5**	-30.8 to - 33.7	290					210		80	48°		75-90°	W1-W2	linsen slt 10-25%st (N4)/qtz filled joints
22	**BOX 6**	-33.7 to -36.3	260		71			91	82	16	45°			W1-W2	linsen slt 10&st (N4)/flaser 80-97%st (N3-B5)/network of thin (<3mm) joints, 10 qtz filled joints in 2 sets
23	**BOX 7**	-36.3 to -39.05	275					210		65	50-55°		60, 80-90°	W1-W2	flaser 70%st (N2-N4), network of closely spaced joints
24	**BOX 8**	-39.05 to -41.55	250					15	219	16	45°		65, 70, 80°	W1-W2	linsen slt 20-40%st, (N2-N3)
25	**BOX 9**	-41.55 to -44.15	260		44			58	125	33	35-40°		60°	W1-W2	mst fractured/flaser 65,95%st/linsen slt 15, 20%st/slt N2-N3, st-N6/vertical fractures/fault in Box c characterised by intense qtz veins
26	**BOX 10**	-44.15 to -46.85	270					28	135	107	45°		45°	W1-W2	flaser 70%st/linsen slt 40-50%st
27	**BOX 11**	-46.85 to -49.55	270		61	13		158		38	45°		50, 60, 70°	W1-W2	flaser 60-80%st/sts md laminations and locally strongly burrowed/9 thin (<2mm) qtz veins, linsen N2, sts N6-N7
28	**BOX 12**	-49.55 to -52.15	260	22	98	70		70			45°		50, 75°	W1-W2	6 qtz veins/network of veins and fractures/
29	**BOX 13**	-52.15 to -54.8	265						261	4	45°		60, 70°	W1-W2	linsen slt 15%st/fault in Box c parallel to bedding/5 qtz veins
30	**BOX 14**	-54.8 to -57.55	275		10			119	83	63	45°		40, 60, 70, 80°	W1-W2	linsen slt 25%st (N2-N3)/flaser 85%st (N6)/12 qtz veins?>fault in Box b
31	**BOX 15**	-57.55 to -60.0	245		194			49		2	45°		65°	W1-W2	mst burrowed/ flaser 70, 75%st/2 qtz filled joints
32															
33	**TOTALS cm**		4065	22	891	83	43	1008	1291	727	Av. 45.2°				**CONCLUSION: This core is probably from the Cuskinny Member**
34	**TOTALS %**			0.54	21.92	2.04	1.06	24.8	31.76	17.89					
35															
36	**BH07-EC2**	**DEPTH mOD**	**BOX THICKNESS cm**	**FINE STN**	**MED STN**	**SILTSTONE**	**CLAYSTONE**	**FLASER**	**LINSEN**	**GAPS/BROKEN/WEATHERED/NI**	**BEDDING**	**CLEAVAGE**	**JOINTS**	**WEATHERING**	**NOTES**
37	**BOX 1**	-16.9 to -23.5	660		52			77		531	30°			W1-W2	all grey/flaser 85-95%st/upper 125cm pebbles and cobbles/very brolen core/iron staining on joints/qtz veins parallel to bedding
38	**BOX 2**	-23.5 to -26.3	280		161			54	5	60	10-20°		30, 60, 90°	W1-W2	all greenish grey/scattered md streaks in sts/16qtz veins along joints/extensive iron staining on joints
39	**BOX 3**	26.3 to - 29.15	285		259					26	10-15°		55, 80-90°	W1-W2	greenish grey sts/sts massive with isoltred md streaks
40	**BOX 4**	-29.15 to -32.05	290		215			16	16	43	10-15°			W1-W2	greenish grey st with 9 md streaks/extenisve iron staining on joints/4 qtz filled veins/very broken core/ linsen brecciated/flaser has qtz veins/mst occassional md flakes
41	**BOX 5**	-32.05 to -35.15	310		164					146	0-10°		30, c.60°	W1-W2	very broken core/greenish grey mst with minor md streaks
42	**BOX 6**	-35.15 to -38.2	305	60	123			49		73	10-20°			W1-W2	greenish grey mst/flaser 90%st/qtz veins
43	**BOX 7**	-38.2 to -40.9	270		128	50	27		42	23	10-30/90°			W1-W2	bedding dip: Box 7a-10-15°, Box 7b-10-15°, 30° at base, Box 7c-90°/greenish grey mst, massive with minor laminations and md levels/grey slts
44	**BOX 8**	-40.9 to -43.7	280			125			95	60	60°			W1-W2	grey (N4-N5) slt and Linsen/linsen 10-30%st/3 qyz veins/
45	**BOX 9**	-43.7 to -46.3	260		176					84	60°		60°	W1-W2	grey massive, locally laminate mst, top 70cm-fine to medium grained/2 joint sets intersecting/joints filled with qtz/extensive qtz veins/ very fractured core/
46	**BOX 10**	-46.3 to -49.3	300		284					16	75-85		75°	W1-W2	grey mst/very fractured along steep bedding
47	**BOX 11**	-49.3 to -52.2	290		192					98	80-85°		30°	W1-W2	grey (N6) mst/1-3mm md streaks throughout/very fractured along steep bedding
48	**BOX 12**	-52.2 to -55	280		275					5	80°		30, 50°	W1-W2	grey mst with 1-2mm md streaks throughout/Box 10c-extensive vertical to subvertical fracturing following bedding planes/20mm qtz vein
49															
50	**TOTALS cm**		3810	60	2029	175	27	196	158	1165	Av.15°/75°				**CONCLUSIONS:**
51	**TOTALS %**			1.58	53.25	4.6	0.71	5.12	4.15	30.58	99.99				**This core is probably from the Cuskinny Member**
52															**A possible significant fault at -39.55mOD separates the two zones of bedding dip. If present the fault plane would be inclined at an angle possibly less tha c.60°**
53															
54															**ABBREVIATIONS**
55															md-mudstone (siltstone/claystone/slt-siltstone), cl-claystone, slt-siltstone, fst-fine-grained sandstone, mst-medium-grained sandstone. Qtz-quartz
56															Box a-upper box, Box B-middle box, Box c-lower box

Fig 14.3. Summary of bedrock geological characteristics of RC05-EC2 to RC07-EC2.

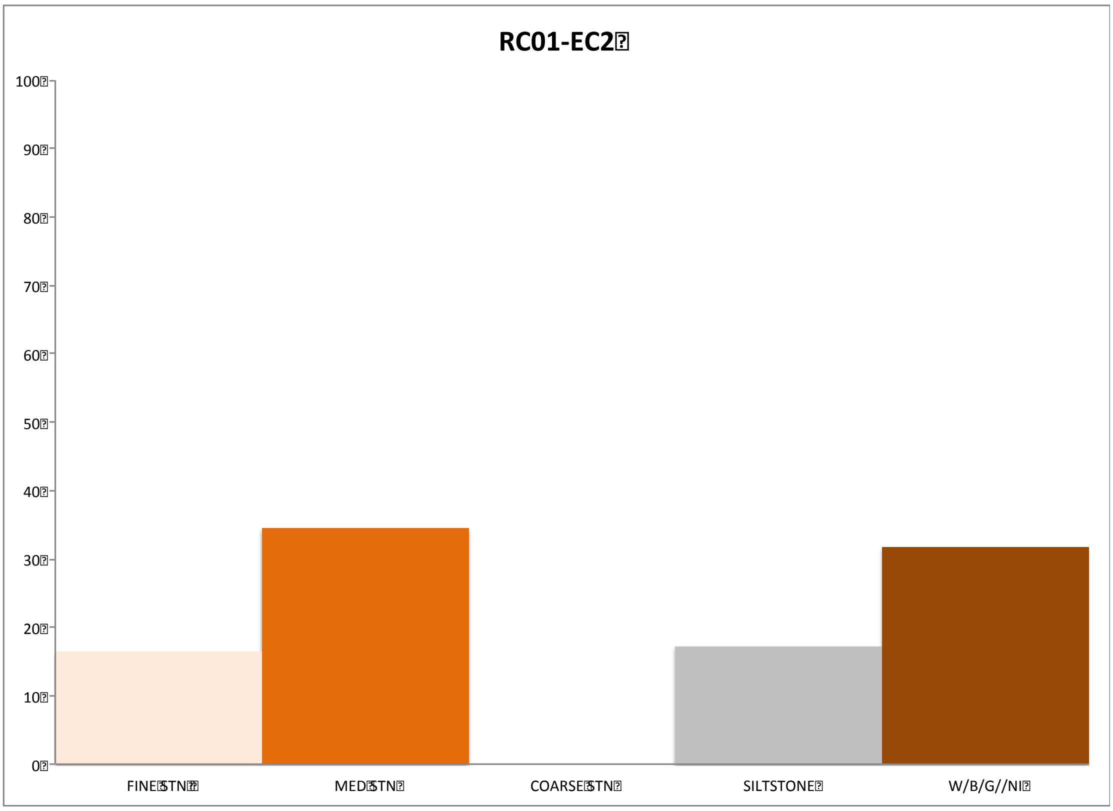


Fig 14.4. Histogram of lithologies in RC01-EC2 (Gyleen Formation).
W/B/G/NI-Weathered, Broken, Gaps or Non-Intact levels.
Vertical Scale shows percentage.

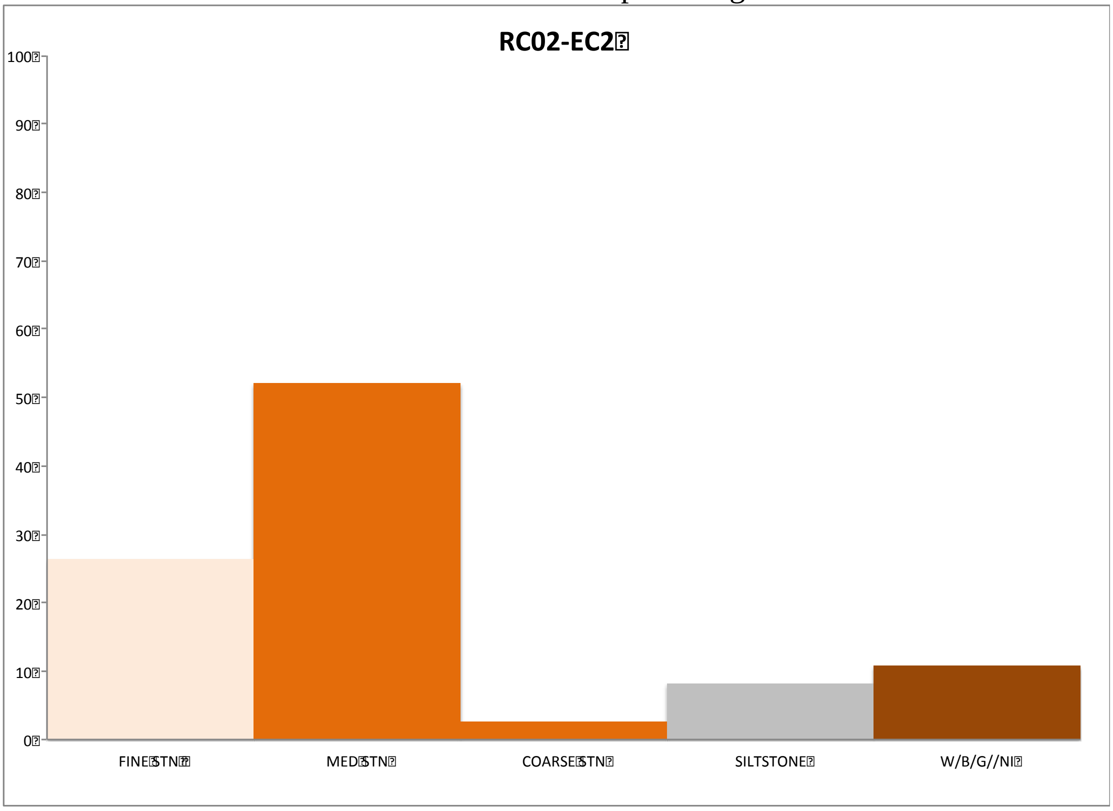


Fig 14.5. Histogram of lithologies in RC02-EC2 (Gyleen Formation Ballyknock Member). W/B/G/NI-Weathered, Broken, Gaps or Non-Intact levels.
Vertical Scale shows percentage.

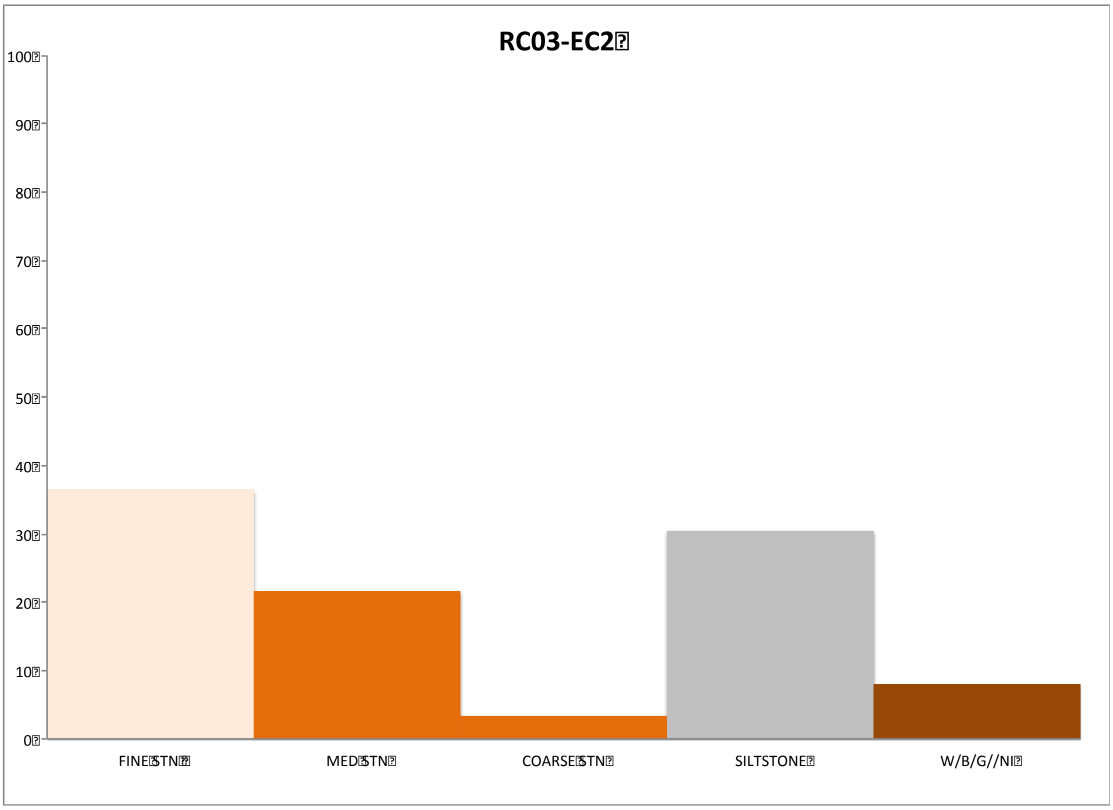


Fig 14.6. Histogram of lithologies in RC03-EC2
(Gyleen Formation Ballyknock Member).
W/B/G/NI-Weathered, Broken, Gaps or Non-Intact levels.
Vertical Scale shows percentage.

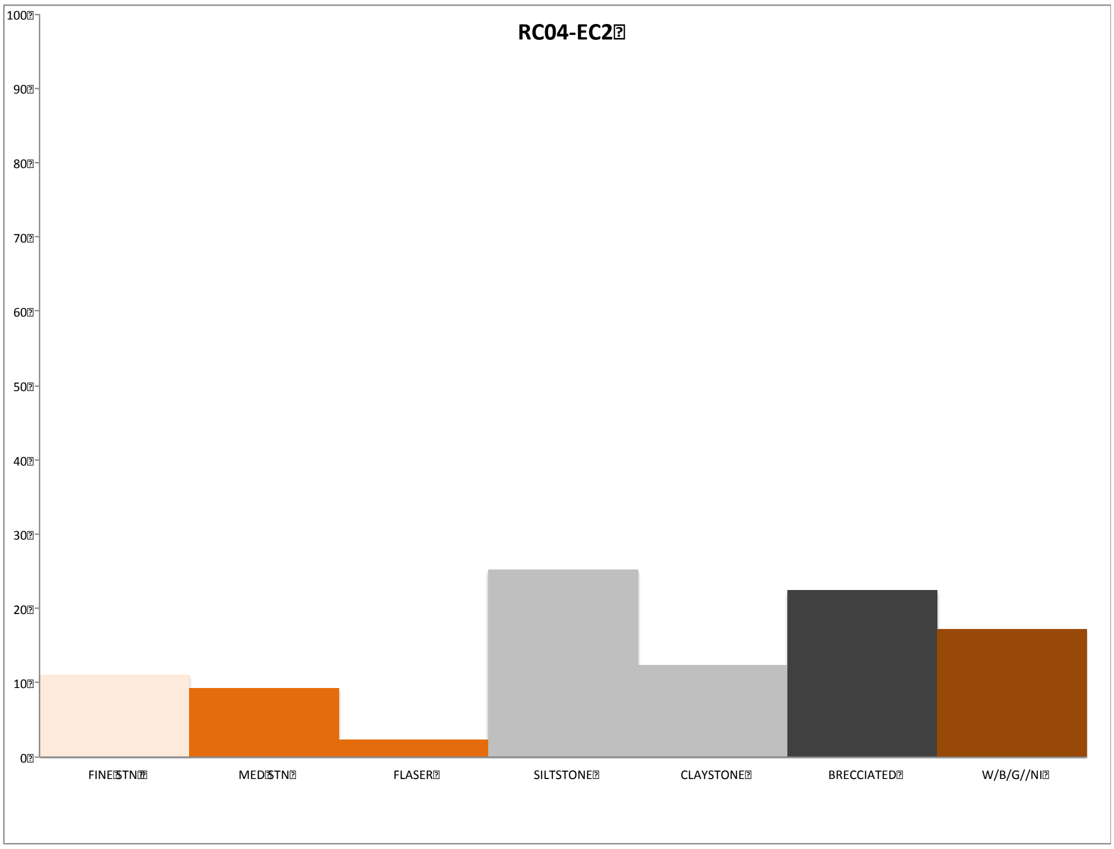


Fig 14.7. Histogram of lithologies in RC04-EC2.
Kinsale Formation Castle Slate Member/Gyleen Formation Ballyknock Member.
W/B/G/NI-Weathered, Broken, Gaps or Non-Intact levels
(including fault gouge zone). Vertical Scale shows percentage.

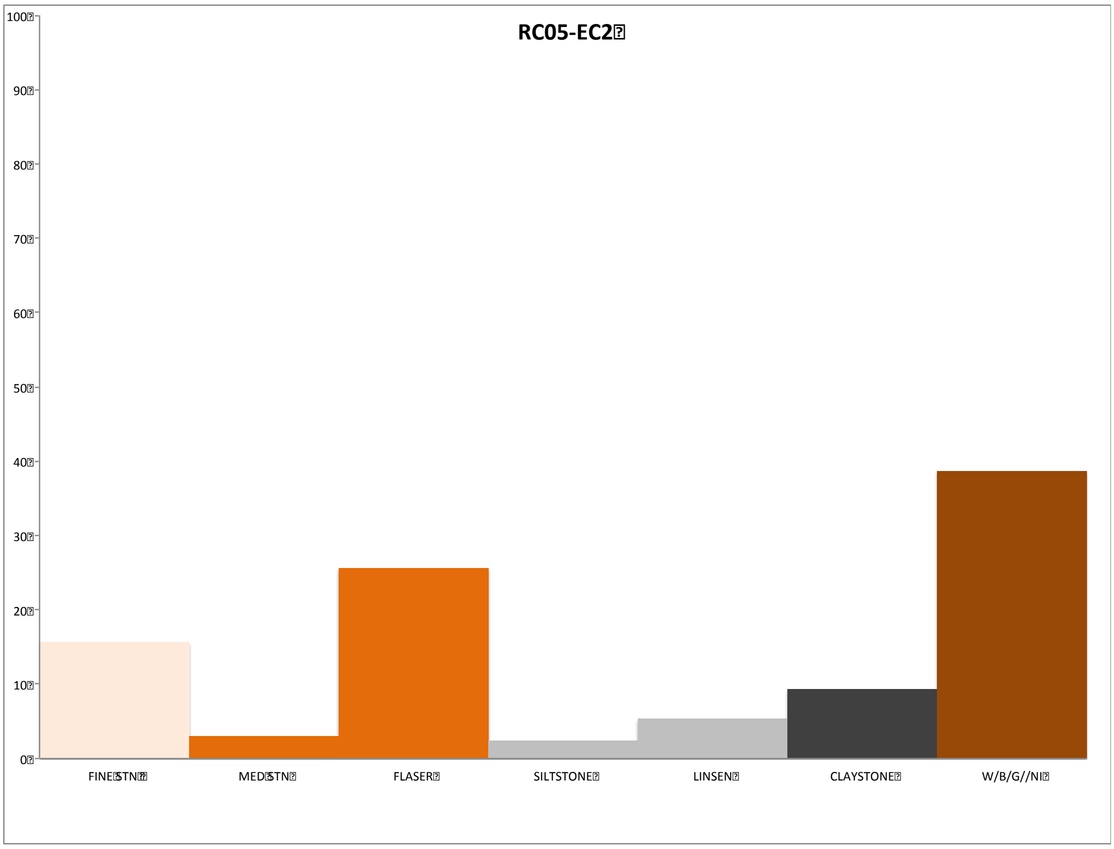


Fig 14.8. Histogram of lithologies in RC05-EC2.
Kinsale Formation Cuskinny Member.
W/B/G/NI-Weathered, Broken, Gaps or Non-Intact levels
Vertical Scale shows percentage.

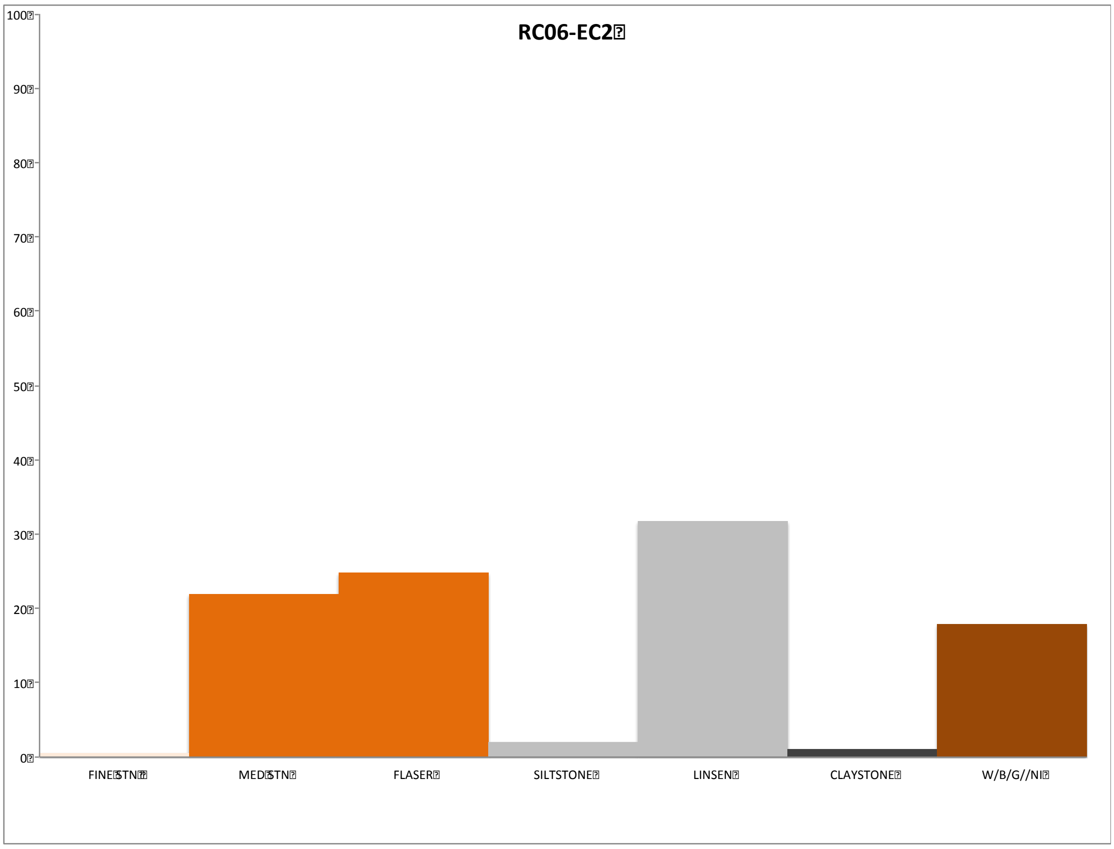


Fig 14.9. Histogram of lithologies in RC06-EC2.
Kinsale Formation Cuskinny Member.
W/B/G/NI-Weathered, Broken, Gaps or Non-Intact levels
Vertical Scale shows percentage.

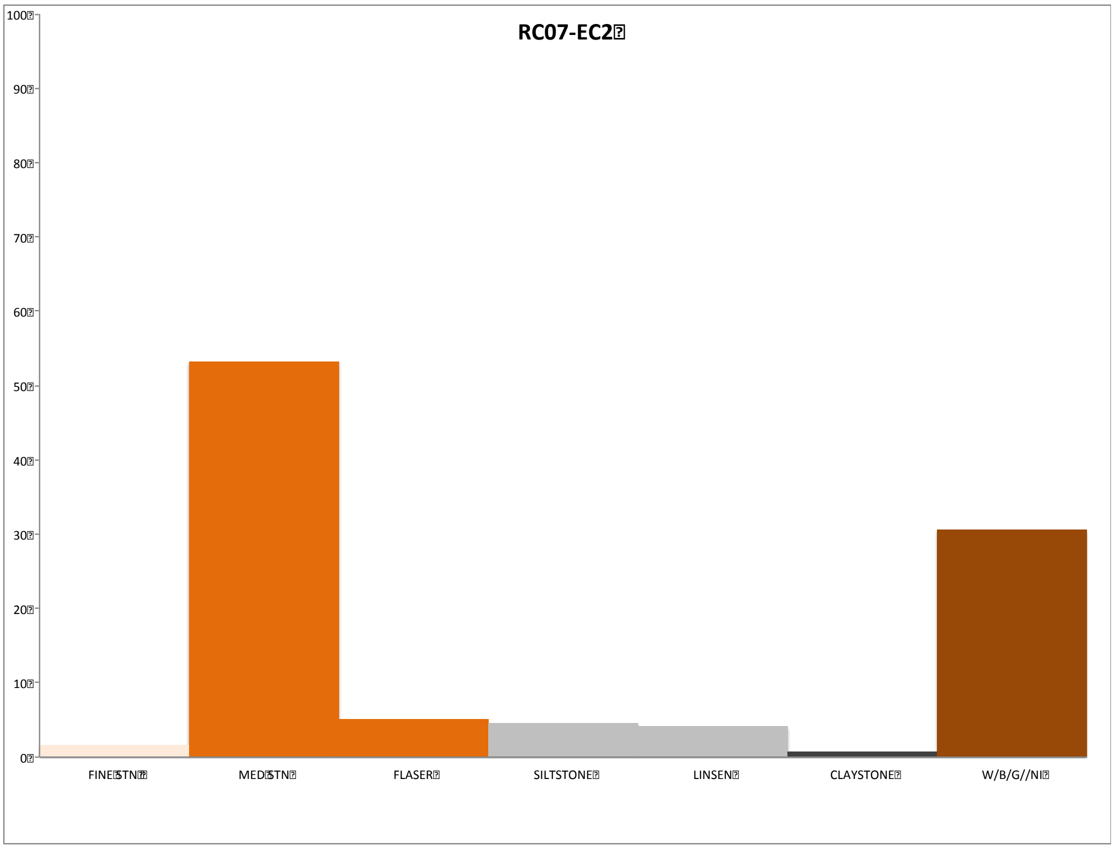


Fig 14.10. Histogram of lithologies in RC07-EC2.
Kinsale Formation Cuskinny Member
Vertical Scale shows percentage.

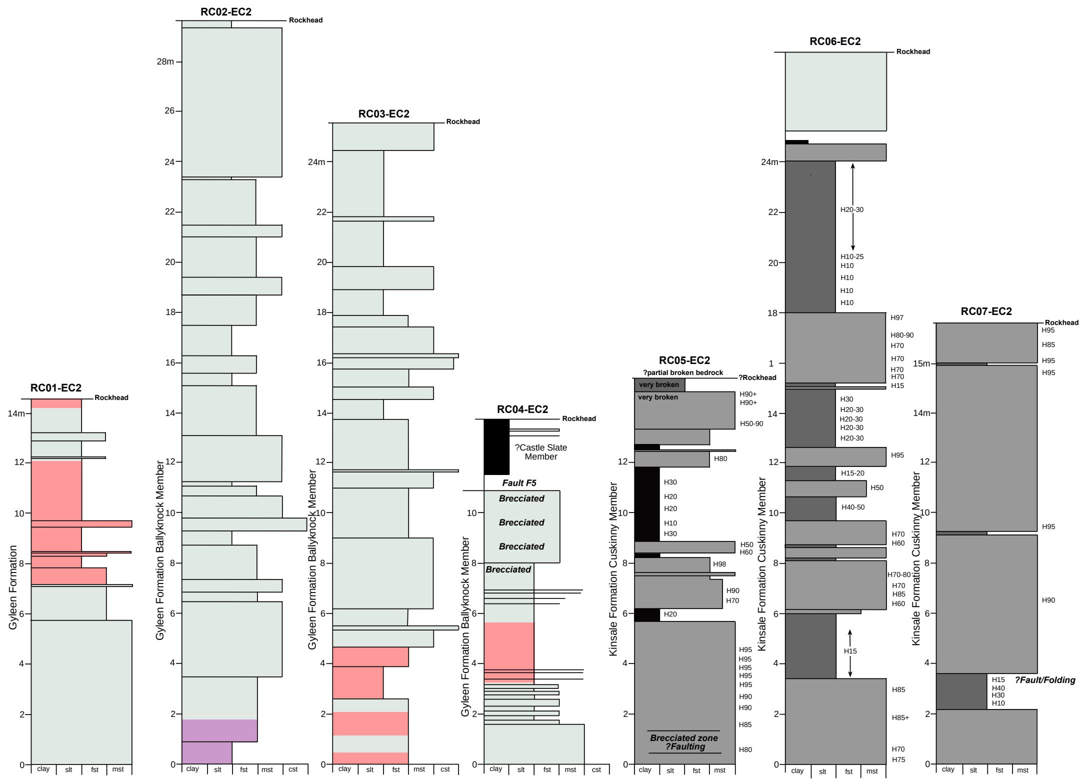


Fig 14.11. Schematic lithostratigraphical logs of the bedrock intersected in Boreholes RC01-EC2 to RC07-EC2. This depicts the preserved original thickness of the sedimentary layers or beds, as seen in the recovered core from each borehole, taking into account their structural dip. Differences between the thicknesses shown here and downhole thicknesses are due to a combination of the effect of varying structural bedding dip and incomplete core recovery.

The colours shown represent the general colours of the bedrock.

H-Heterolithic (Flaser/Linsen Bedding). The appended numbers (e.g. H20) record the percentage sandstone in the heterolithic levels.

The scale shown in metres is approximate.

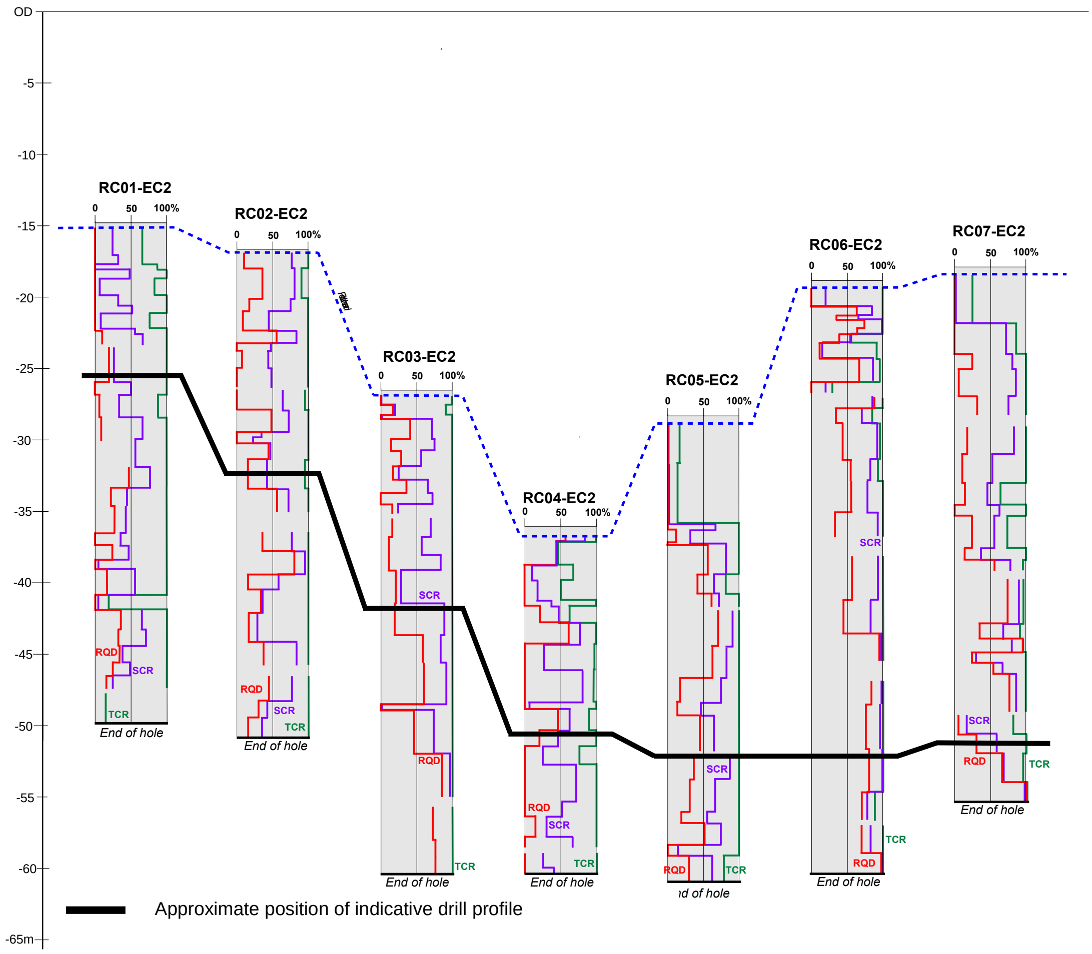


Fig 15.1. Summary logs showing (a) TCR (green), SCR (purple) and RQD (red) for RC01-EC2 to RC07-EC2 and
(b) Rockhead profile (blue line) along estuary crossing
(based on *Priority Geotechnical* core logs dated June 2016).

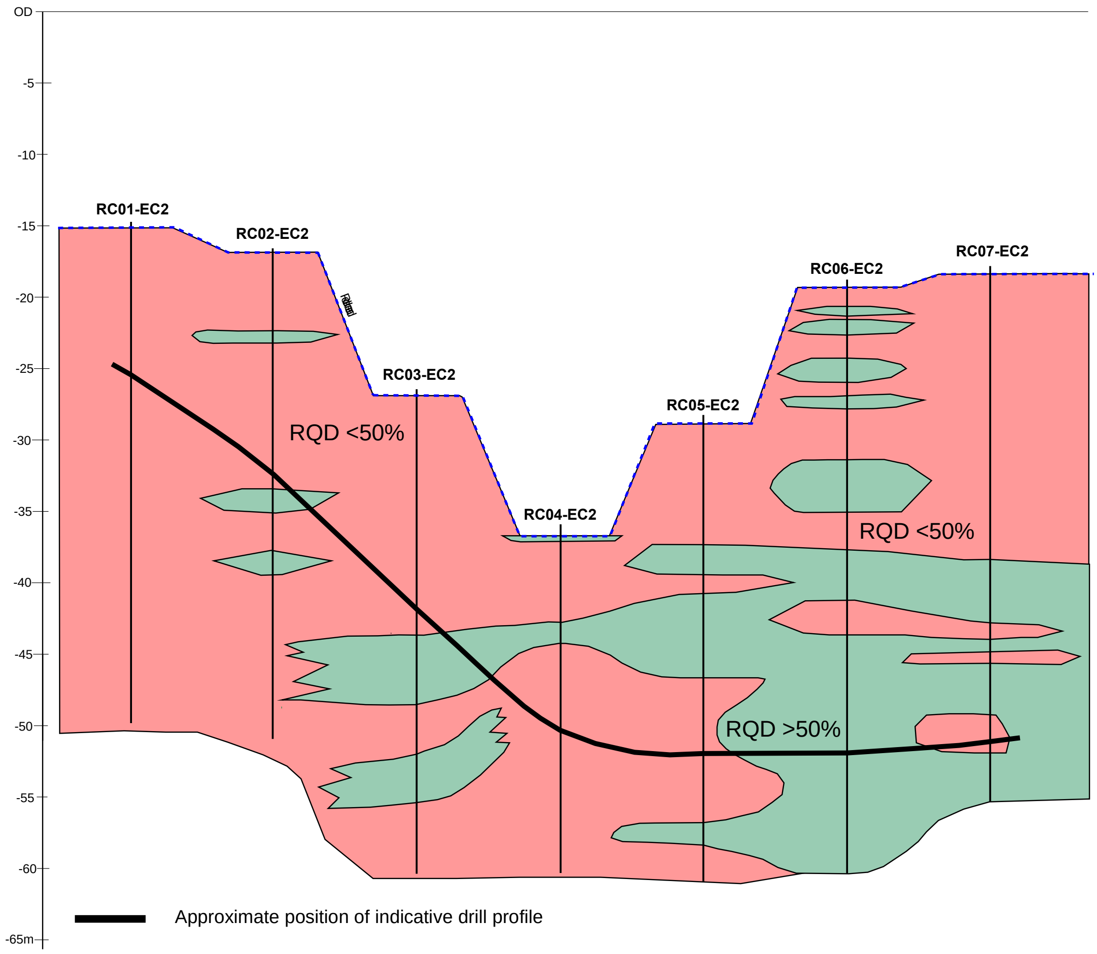


Fig 15.2. Cross-section of the estuary crossing showing the rock quality (RQD) distribution pattern in RC01-EC2 to RC07-EC2 boreholes (based on *Priority* Core logs dated June 2016).
In view of the variable pattern of RQD values in the bedrock in this region, correlations/extrapolations shown here between boreholes are speculative only.

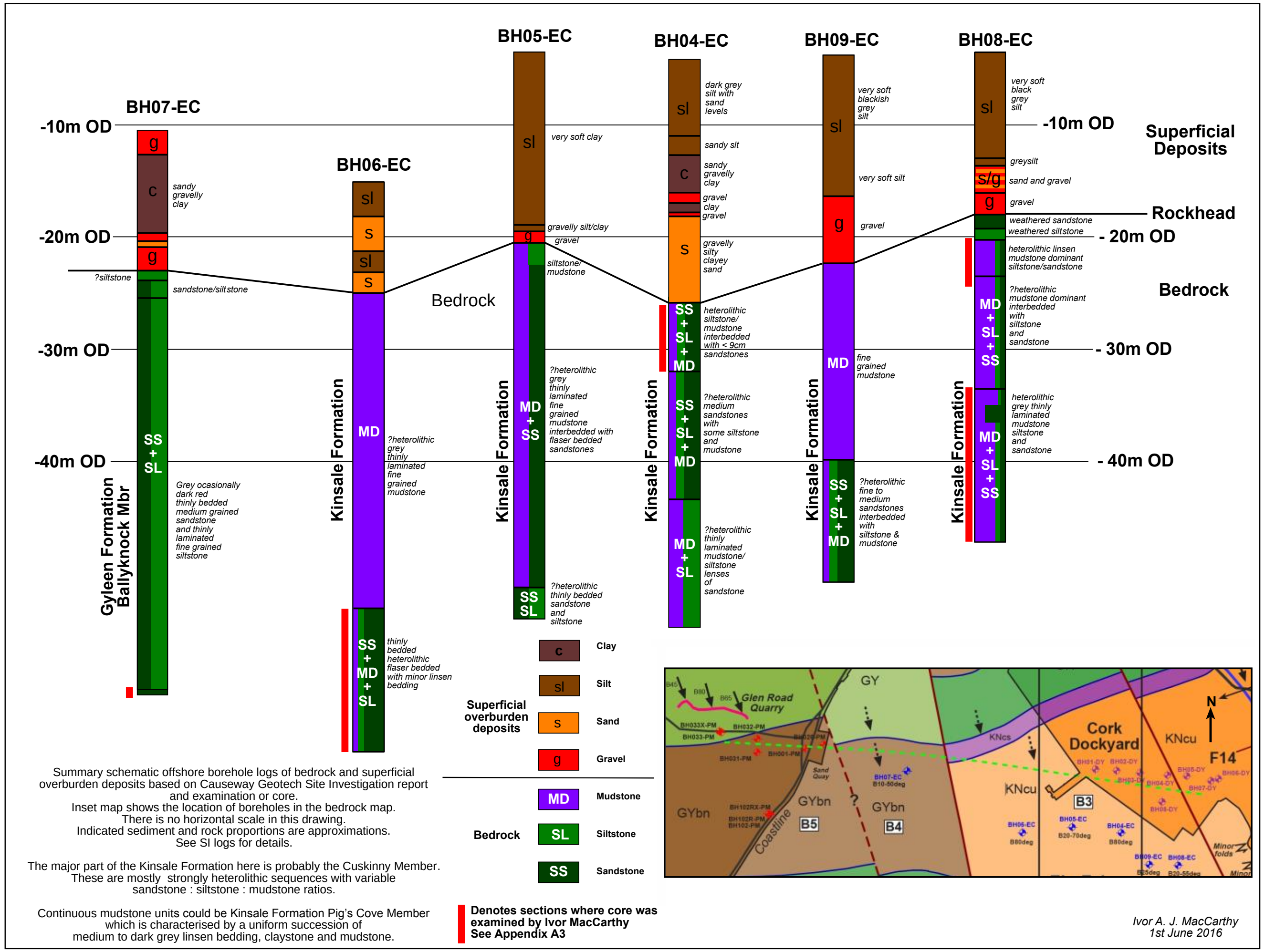


Fig 16.1. Summary offshore EC borehole logs.

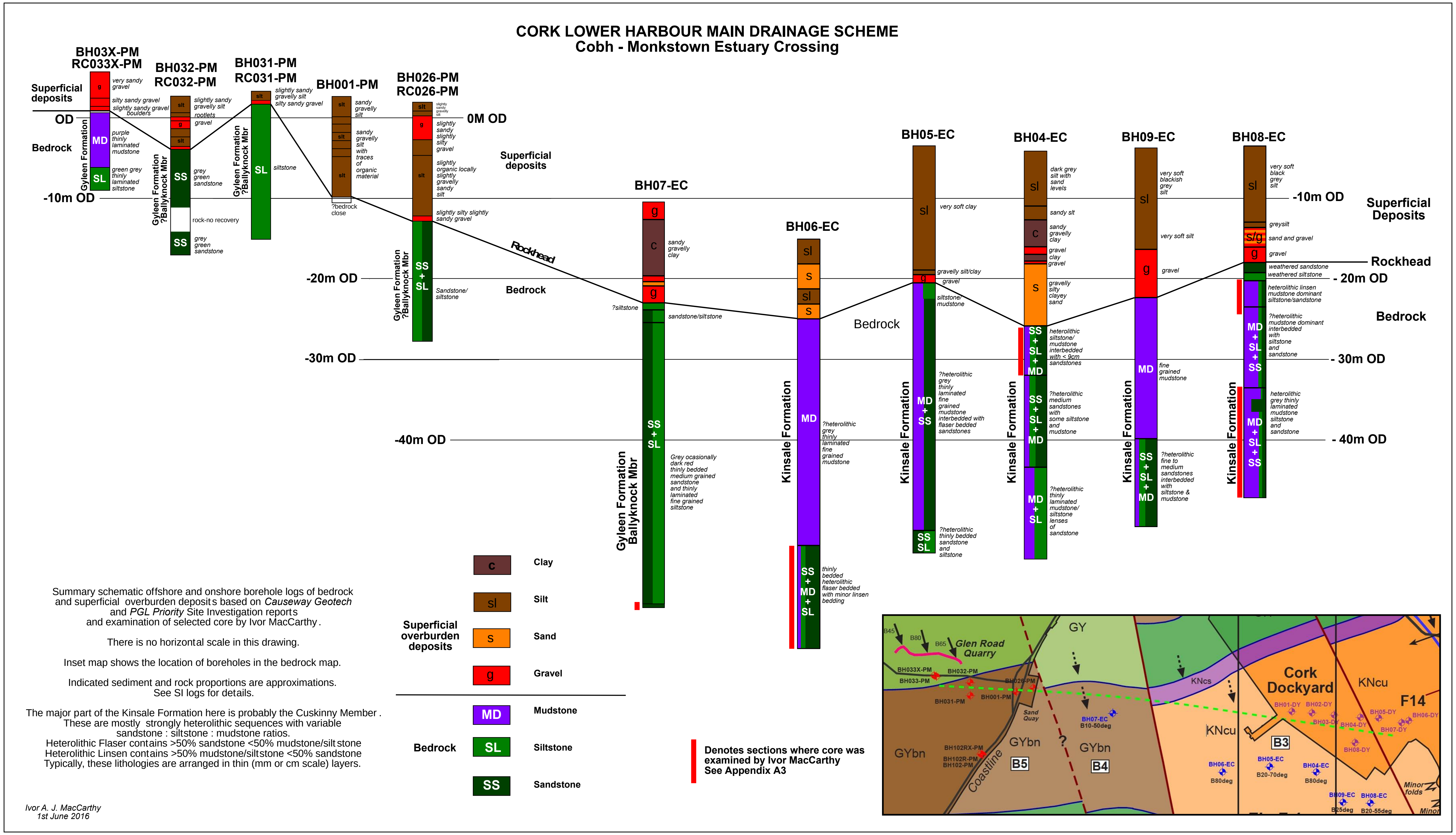


Fig 16.2. Summary of Monkstown onshore PM to offshore EC borehole logs.

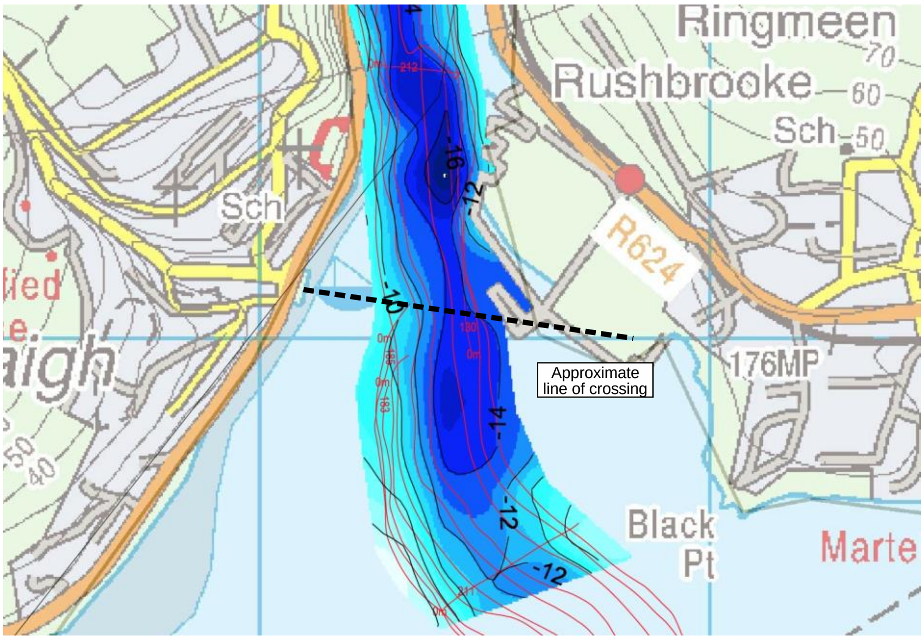


Fig 17.1. Seabed map of the Cobh to Monkstown crossing area.

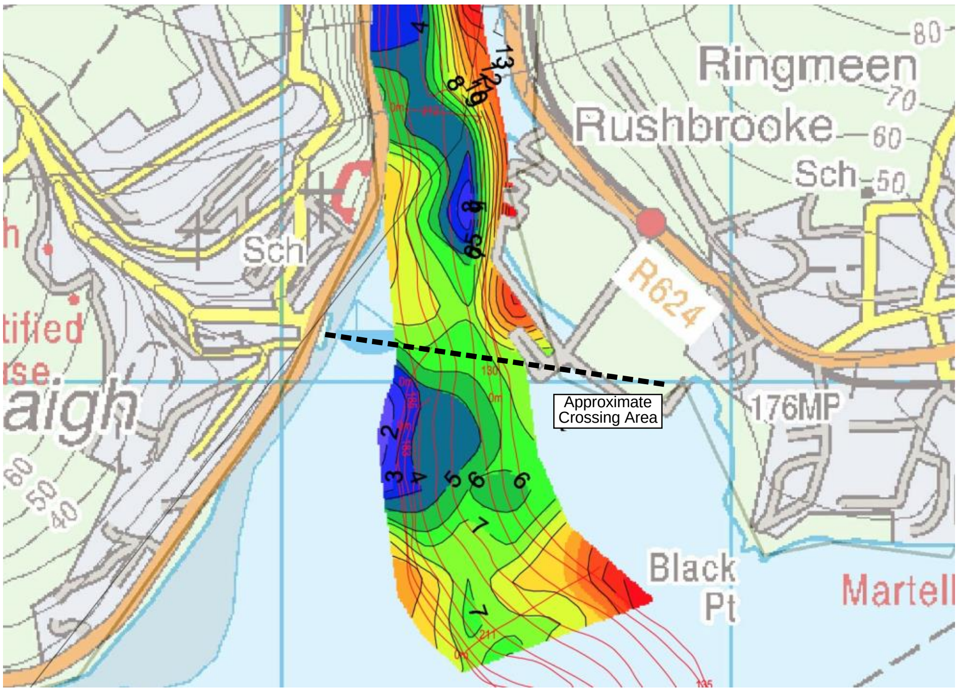


Fig 17.2. Overburden thickness in the Cobh to Monkstown crossing area.

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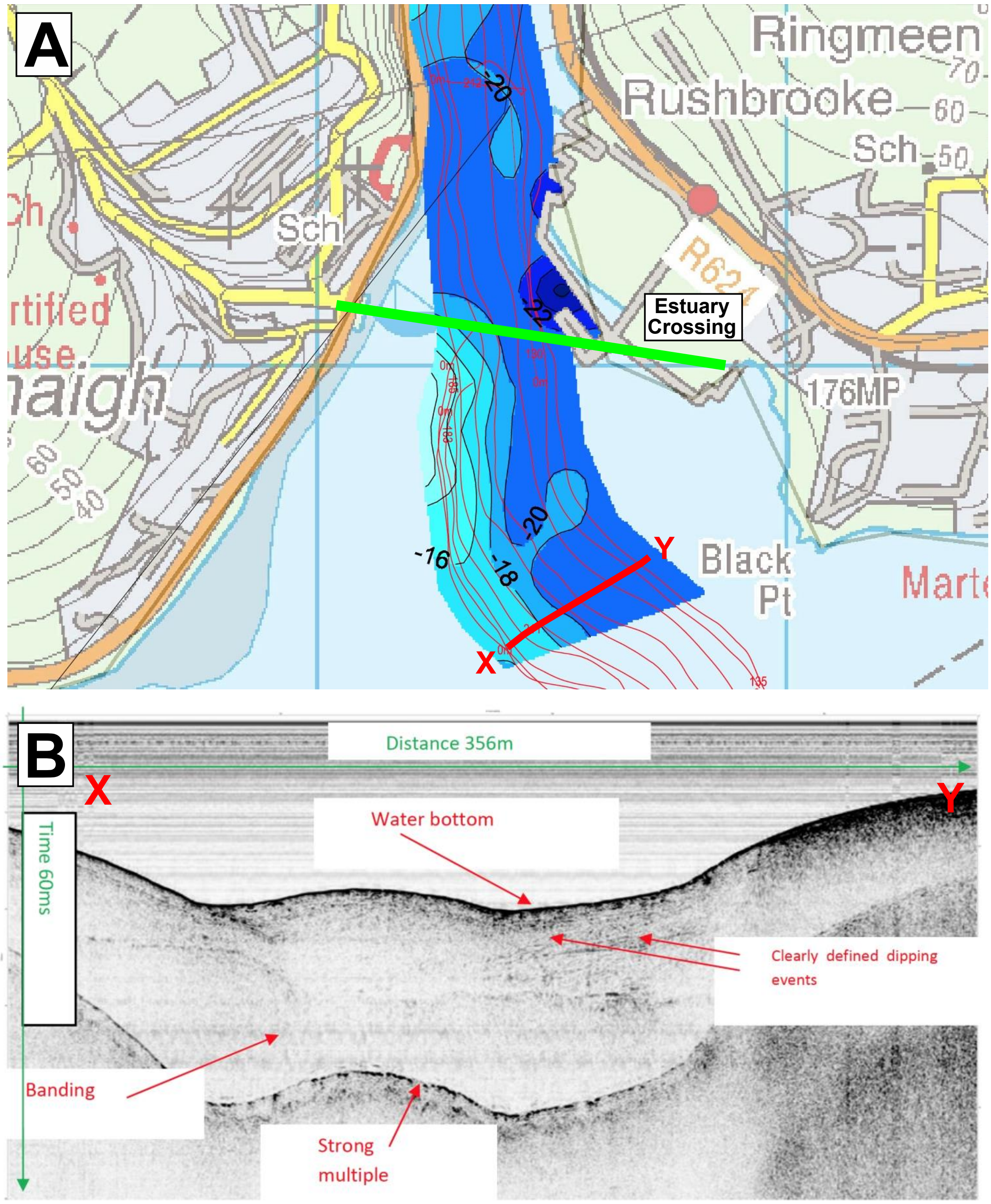


Fig 17.3. A-Depth to bedrock in the Cobh to Monkstown estuary crossing area (*Apex Geoservices* 26th June 2013). Note: The depth to bedrock shown here is less than indicated by the borehole information (see Fig 11.1). (B)-CHIRO seismic profile along the line X-Y in Fig 16.3A-The 'strong multiple' may reflect horizons in the lower parts of the superficial deposits and/or parts of the rockhead zone.

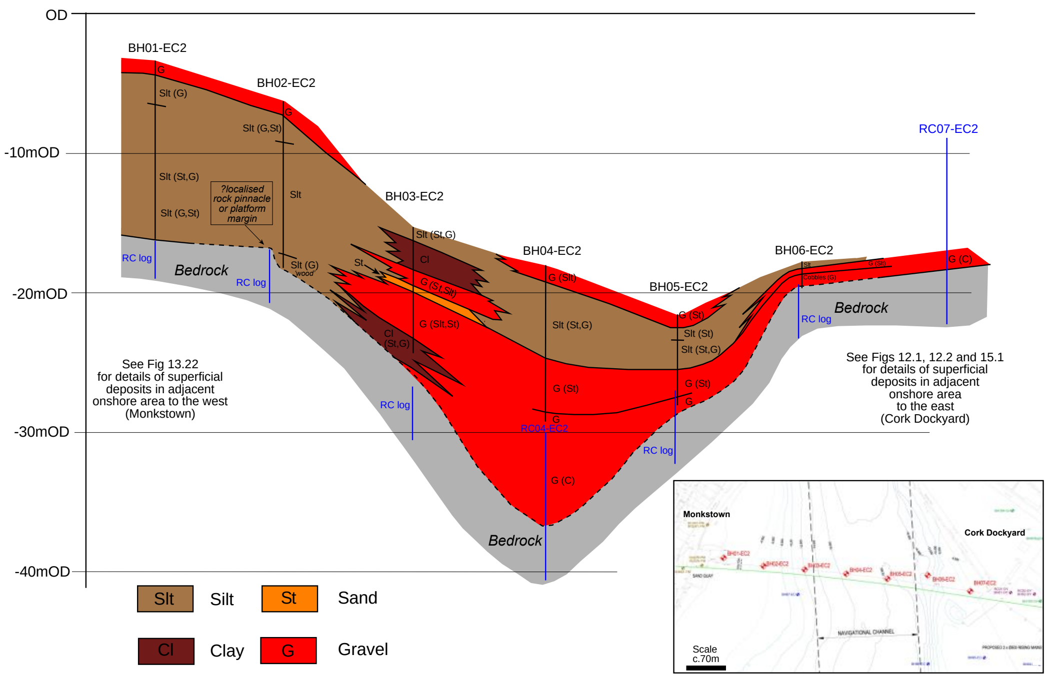


Fig 17.4. Distribution pattern of superficial deposits in the offshore area adjacent to the estuary crossing in Boreholes BH01-EC2 to BH06-EC2, RC04-EC2 and RC07-EC2. Sediment abbreviations in brackets indicate the presence of subsidiary sediments grades, e.g. Slt (St, G) indicates Sandy gravelly Silt etc.

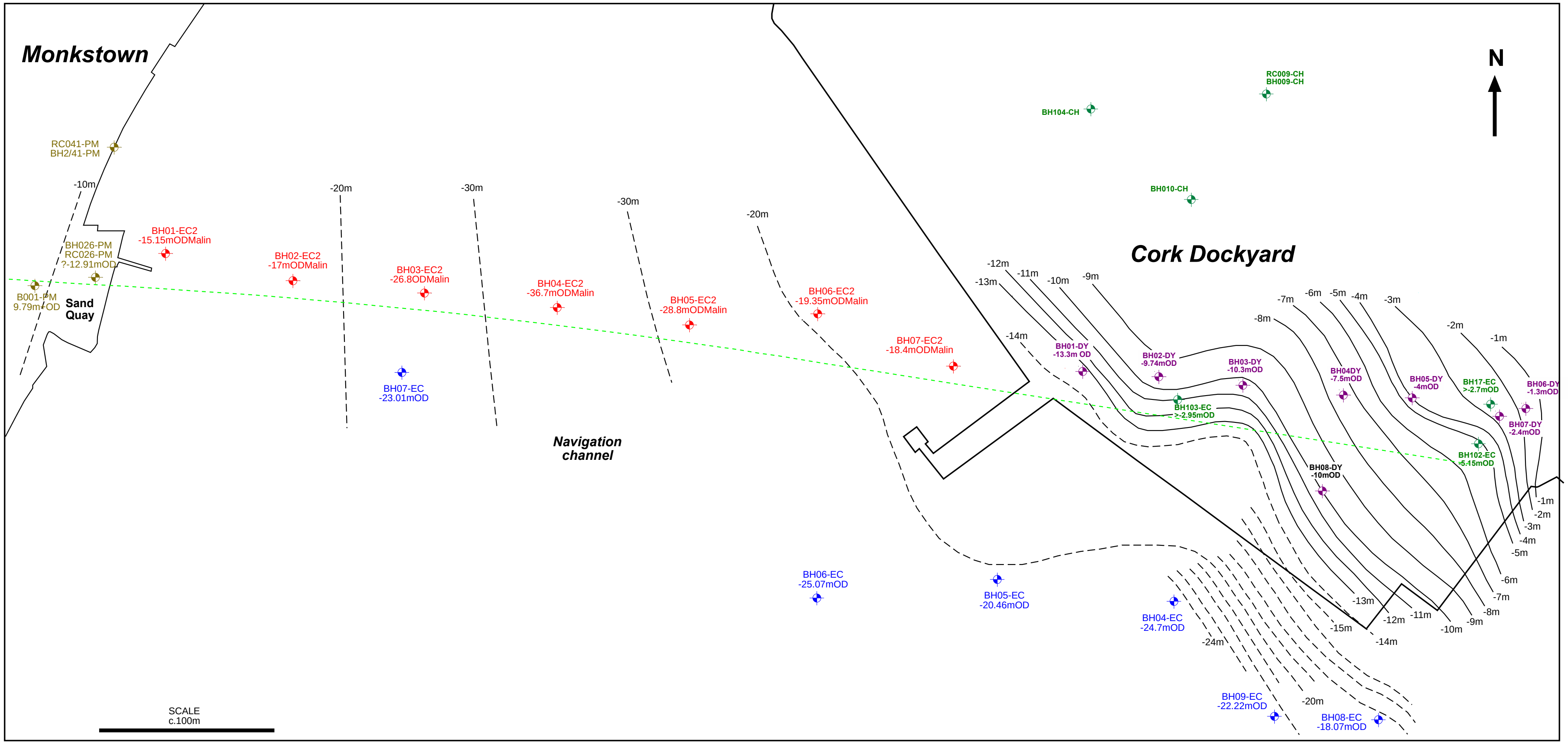
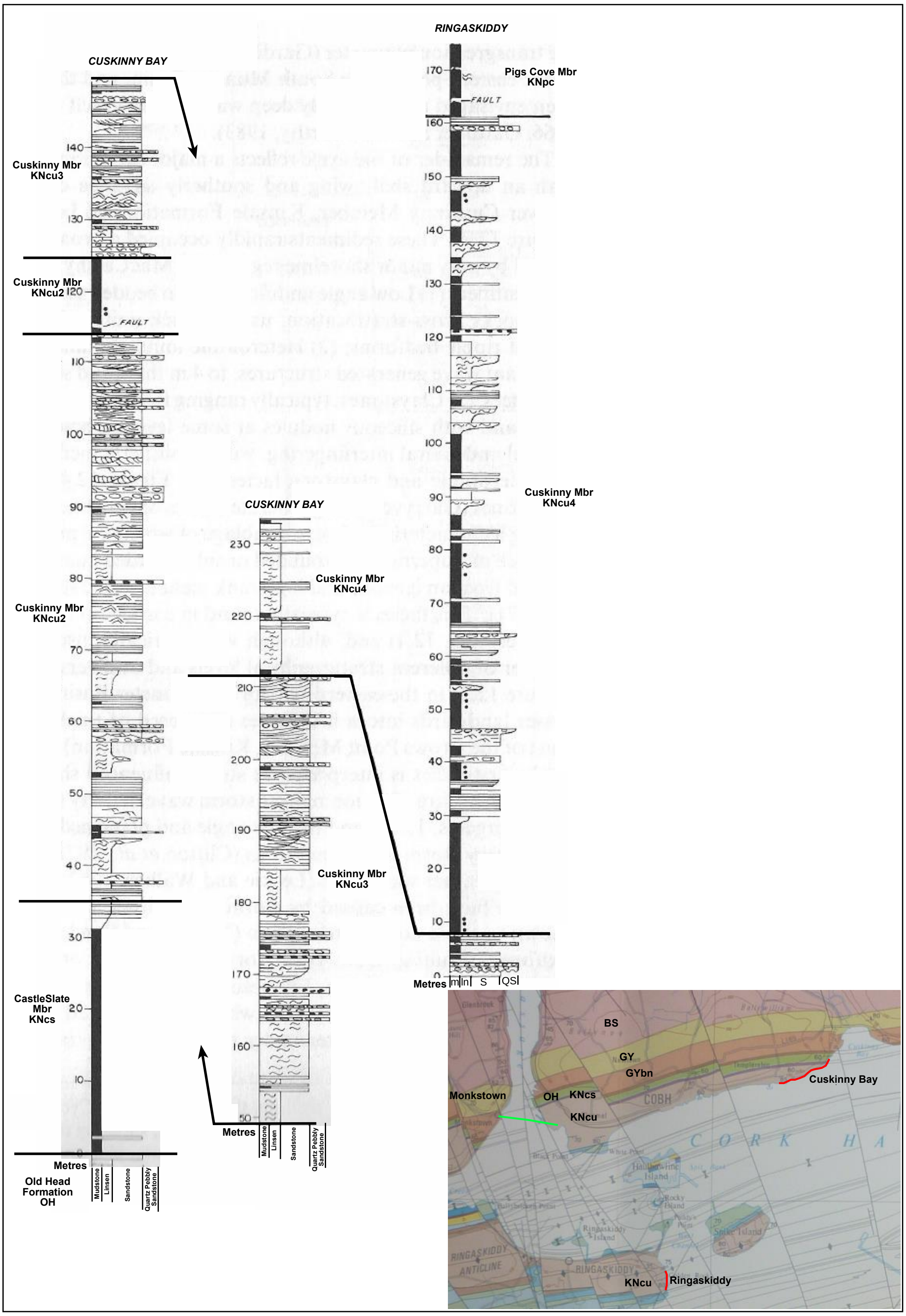


Fig 11.1. (Duplicate). Interpreted contours of the rockhead in the Cobh-Monkstown estuary crossing area.

<u>PART H-APPENDICES</u>

APPENDIX A-Supplementary Data

Appendix A1. Log of the Kinsale Formation in Cuskinny Bay and Ringaskiddy (red lines). A similar lithological sequence would be expected in the Cobh-Monkstown estuary crossing (green line).



Appendix A2-Palynological analyses

Samples supplied to UCC for processing.

RC01-DY-Box 8/42.0m
RC01-DY-Box 9/48.1m
RC01-DY-Box10/49.7m
RC02-DY-Box 12/47.7m
RC02-DY-Box 6/31.3m
RC05-DY-Box 9/35.75m
RC07-DY-Box 3/11.5m
RC08-DY-Box 2/20.2m
RC08-DY-Box 5/28.8m
RUSH 01-Railway section (See Fig 4)
RUSH 02-Railway section (See Fig 4)

Palynology analysis of Rushbrooke samples-Report by Professor Ken Higgs, School of Biological Earth and Environmental Sciences, UCC.

Twelve mudrock core samples were processed for palynological analysis. The laboratory preparation of the samples was carried out by Ms Mary Lehane, Senior Technician in the School of Biological Earth and Environmental Sciences, UCC.

Microscope analysis and biostratigraphical age determinations were carried out by Professor Ken Higgs, School of Biological Earth and Environmental Sciences, UCC.

(1) All of the samples analysed are early Carboniferous in age and can be assigned to the Kinsale Formation.
(2) The spore assemblage recorded in each sample is listed separately and the spore species identified are those described in Higgs et al. (1988).
(3) The samples were biostratigraphically dated using the Late Devonian and Carboniferous spore zonation scheme described by Higgs et al. (1988) and subsequently refined by Higgs & Forsythe (2008) for the South Munster Basin succession (see Spore zonations below).

<u>References</u>

Higgs, K.T., Clayton, G. & Keegan, J.B. 1988.
Systematic and Stratigraphicpalynology of the Tournaisian rocks of Ireland.
Special Paper Geol. Surv. Ireland, 7, 110pp.

Higgs, K. T. & Forysthe, E. 2008
Mississippian microfloras from the South Munster Basin, Ireland.
Comunicações Geológicas, 94, 177-195

RC01 DY Box 8 / 42.0m

Assemblage list of spore taxa

Auroraspora corporiga
Auroraspora granulatipuntata
Auroraspora minor
Convolutispora calignosa
Convolutispora vermiformis
Corbulispora cancellata
Crassispora cf. *maculosa*
Bascaudaspora submarginata
Grandispora echinata
Indotriradiates explanatus
Cristatisporites hibernicus
Plicatispora scolecophora
Plicatispora quasilabrata
Punctatisporites irrasus
Pustulalatisporites dolbii
Raistrickia vaiabilis
Retusotriletes incohatus
Tumulispora rarituberculata
Verrucosisporites nitidus
Verrucosisporites oppressus

Spore Biozone : HD Biozone (lower)
Stratigraphical assignment : Kinsale Formation, Member 2 (Cuskinny Member)

RC01 DY Box 9 / 48.1.0m

Assemblage list of spore taxa

Auroraspora corporiga
Auroraspora granulatipuntata
Auroraspora minor
Convolutispora calignosa
Corbulispora cancellata
Crassispora cf. *maculosa*
Bascaudaspora collicula
Bascaudaspora submarginata
Grandispora echinata
Indotriradiates explanatus
Cristatisporites hibernicus
Cristatisporites matthewsii
Plicatispora scolecophora
Plicatispora quasilabrata
Punctatisporites irrasus
Pustulalatisporites dolbii
Raistrickia vaiabilis
Raistrickia minor
Retusotriletes crassus
Retusotriletes incohatus
Tumulispora raritaberculata
Verrucosisporites nitidus
Verrucosisporites oppressus

Spore Biozone : HD Biozone (lower)
Stratigraphical assignment : Kinsale Formation, Member 2 (Cuskinny Member)

RC01 DY Box 6 / 42.0m

Assemblage list of spore taxa

Auroraspora corporiga
Auroraspora granulatipuntata
Auroraspora minor
Convolutispora vermiformis
Crassispora cf. *maculosa*
Bascaudaspora submarginata
Grandispora echinata
Indotriradiates explanatus
Cristatisporites hibernicus
Plicatispora scolecophora
Punctatisporites irrasus
Pustulalatisporites dolbii
Raistrickia vaiabilis
Retusotriletes incohatus
Tumulispora rarituberculata
Verrucosisporites nitidus

Spore Biozone : HD Biozone (lower)
Stratigraphical assignment : Kinsale Formation, Member 2 (Cuskinny Member)

RC02 DY Box 6 / 31.3m

Assemblage list of spore taxa

Auroraspora corporiga
Bascaudaspora submarginata
Convolutispora vermiformis
Crassispora cf. *maculosa*
Cyrtospora cristifer
Bascaudaspora submarginata
Grandispora echinata
Cristatisporites hibernicus
Plicatispora scolecophora
Punctatisporites irrasus
Pustulalatisporites dolbii
Raistrickia vaiabilis
Raistrickia minor
Retusotriletes crassus
Retusotriletes incohatus
Spelaeotriletes obtusus
Tumulispora rarituberculata
Verrucosisporites nitidus

Spore Biozone : HD Biozone (lower)
Stratigraphical assignment : Kinsale Formation, Member 2 (Cuskinny Member)

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RC02 DY Box 12 / 47.7m

Assemblage list of spore taxa

Auroraspora corporiga
Crassispora cf. maculosa
Plicatispora scolecophora
Punctatisporites irrasus
Pustulalatisporites dolbii
Retusotriletes incohatus
Verrucosisporites nitidus

Spore Biozone : VI Biozone or younger (Note: This is a tentative assignment due to the small number of taxa identified, it might be younger)
Stratigraphical assignment : Kinsale Formation, Member 1 (Castle Slate Member).
In view of the setting of this borehole, this is more probably Cuskinny Member.
IMC

RC05 DY Box 9 / 35.75m
Assemblage list of spore taxa

Auroraspora corporiga
Auroraspora minor
Corbulispora cancellata
Crassispora cf. *maculosa*
Bascaudaspora submarginata
Grandispora echinata
Cristatisporites hibernicus
Plicatispora scolecophora
Punctatisporites irrasus
Pustulalatisporites dolbii
Raistrickia minor
Raistrickia vaiabilis
Retusotriletes incohatus
Tumulispora rarituberculata
Verrucosisporites nitidus

Spore Biozone : HD Biozone (lower)
Stratigraphical assignment : Kinsale Formation, Member 2 (Cuskinny Member)

RC07 DY Box 3 / 11.5m
Assemblage list of spore taxa

Auroraspora corporiga
Auroraspora granulatipuntata
Convolutispora calignosa
Crassispora cf. *maculosa*
Bascaudaspora submarginata
Cristatisporites hibernicus
Plicatispora scolecophora
Plicatispora quasilabrata
Punctatisporites irrasus
Punctatisporites minutus
Pustulalatisporites dolbii
Raistrickia vaiabilis
Retusotriletes incohatus
Tumulispora rarituberculata
Verrucosisporites nitidus

Spore Biozone : HD Biozone (lower)
Stratigraphical assignment : Kinsale Formation, Member 2 (Cuskinny Member)

RC08 DY Box 2 / 20.2m
Assemblage list of spore taxa

Auroraspora corporiga
Crassispora cf. maculosa
Bascaudaspora submarginata
Plicatispora scolecophora
Plicatispora quasilabrata
Punctatisporites irrasus
Pustulalatisporites dolbii
Raistrickia vaiabilis
Retusotriletes incohatus
Verrucosisporites nitidus

Spore Biozone : VI Biozone or younger (Note: This is a tentative assignment because numerous spore specimens were unidentifiable due poor preservation , so it might be younger)
Stratigraphical assignment : Kinsale Formation, Member 1 (Castle Slate Member).
This must be Cuskinny Mbr as it overlies proven Cuskinny Mbr. (Assuming that this superposition is not structural) IMC

RC08 DY Box 5 / 28.2m
Assemblage list of spore taxa

Auroraspora corporiga
Auroraspora granulatipuntata
Crassispora cf. maculosa
Bascaudaspora submarginata
Plicatispora scolecophora
Punctatisporites irrasus
Pustulalatisporites dolbii
Raistrickia vaiabilis
Retusotriletes incohatus
Tumulispora rarituberculata
Verrucosisporites nitidus

Spore Biozone : VI Biozone or younger (Note : This is a tentative assignment because numerous spore specimens were unidentifiable due poor preservation , so it might be younger)
Stratigraphical assignment : Kinsale Formation, Member 1(Castle Slate Member).
This must be Cuskinny Mbr as it overlies proven Cuskinny Mbr. (Assuming that this superposition is not structural) IMC

RC08 DY Box 9 / 38.5m
Assemblage list of spore taxa

Auroraspora corporiga
Auroraspora granulatipuntata
Auroraspora minor
Convolutispora caliginosa
Convolutispora vermiformis
Crassispora cf. *maculosa*
Bascaudaspora submarginata
Cristatisporites hibernicus
Grandispora echinata
Plicatispora scolecophora
Plicatispora quasilabrata
Punctatisporites irrasus
Pustulalatisporites dolbii
Raistrickia vaiabilis
Retusotriletes incohatus
Tumulispora rarituberculata
Umbonatisporites distinctus
Verrucosisporites nitidus

Spore Biozone : HD Biozone (lower)
Stratigraphical assignment : Kinsale Formation, Member 2 (Cuskinny Member)

RUSH 01
Assemblage list of spore taxa

Auroraspora corporiga
Auroraspora granulatipuntata
Auroraspora minor
Bascaudaspora submarginata
Crassispora cf. *maculosa*
Plicatispora scolecophora
Plicatispora quasilabrata
Punctatisporites irrasus
Pustulalatisporites dolbii
Raistrickia vaiabilis
Retusotriletes incohatus
Tumulispora malevkensis
Umbonatisporites abstrusus
Vallatisporites verrucosus
Verrucosisporites nitidus

Spore Biozone : VI Biozone (middle / upper)
Stratigraphical assignment : Kinsale Formation, Member 1 (Castle Slate Member)

RUSH 02
Assemblage list of spore taxa

Auroraspora corporiga
Auroraspora granulatipuntata
Auroraspora minor
Bascaudaspora submarginata
Convolutisora caliginosa
Crassispora cf. *maculosa*
Grandispora echinata
Indotriradiates explanatus
Plicatispora scolecophora
Plicatispora quasilabrata
Punctatisporites irrasus
Pustulalatisporites dolbii
Raistrickia vaiabilis
Retusotriletes incohatus
Tumulispora malevkensis
Umbonatisporites abstrusus
Vallatisporites verrucosus
Verrucosisporites nitidus

Spore Biozone : VI Biozone (middle / upper)
Stratigraphical assignment : Kinsale Formation, Member 1 (Castle Slate Member)

Series and Stages	Conodonts Goniatites, Forams	Miospore Zone	South Munster Basin Kinsale Sub-basin	Stratigraphy Bantry Sub-basin
Upper Mississippian (Serpukhovian)			White Strand Fmn	
		SO	Mbr 3	Kilmore Fmn
		TK	Mbr 2	East Battery Fmn
	E_1 - E_2	CN (Vm)	Mbr 1	East Point Fmn
Middle Mississippian (Visean)	P_1- P_2	CN (Cc)	Lispatrick Formation	Not exposed
	P_1	VF		
		TC		
		TS	Courtmacsherry Fmn	Reenydonegan Fmn
	Glomodiscus / Uralodiscus	Pu	Mbr 4	Mbr 4
Lower Mississippian (Tournaisian)	*Sc. anchoralis*	CM	Mbr 3	Mbr 3
	P. c. carina		Mbr 2	Mbr 2
	Siphonodella - P. inornatus	PC	Mbr 1	Mbr 1
		BP	Kinsale Fmn	Kinsale Fmn.
			Pigs Cove Mbr	Ardnamanagh Mbr.
		HD	Narrow Cove Mbr	Reenagough Mbr.
				Ardaturrish Mbr.
		VI	Castle Slate Mbr	Castle Slate Mbr
Late Devonian (Strunian)		LN LE LL	Old Head Sandstone Fmn	Old Head Sandstone Fmn

NOTE: The Cuskinny Member (Kinsale Formation) is equivalent to the Narrow Cove Member

MIOSPORE BIOZONE	SUBZONE	STRATIGRAPHY		
		Series	Regional stage	Sub-stage
L. subtriquetra - I. ornatus SO	SR	UPPER MISSISSIPPIAN	Namurian A	Chokierian
	SV			Arnsbergian
S.triangulus - R. knoxi TK				
C. cf. *capistratus - B. nitidus* CN	Vm			Pendleian
	Cc	MIDDLE MISSISSIPPIAN	Viséan	Brigantian
T. vetustus - R. fracta VF				
R. nigra - T. marginatus NM	ME			Asbian
	DP			
P. tessellatus - S. campyloptera TC				
K. triradiatus - K. stephanephorus TS				Holkerian
L. pusilla Pu				Arundian
				Chadian
S. claviger - A. macra CM		LOWER MISSISSIPPIAN	Tournaisian	Ivorian
S. pretiosus - R. clavata PC				
S. balteatus - R. polyptycha BP				
C. hibernicus - U. distinctus HD				Hastarian
V. verrucosus - R. incohatus VI				
R. lepidophyta - V. nitidus LN		UPPER DEVONIAN	Famennian	Strunian
R. lepidophyta - I. explanatus LE				
R. lepidophyta - K.literatus LL				

Appendix A3. Offshore Core Examination Notes (BH04-EC, BH06-EC)

BH04-EC
BOX 1
21.15-22.75m
Siliciclastic non-carbonate
Upper 1m brown gravel.
Heavily weathered heterolithic bedrock under this.
Bedding 80-90.

22.75-24.40m
Siliciclastic non-carbonate
Heterolithic flaser bedding
Bedding 85-90.
KNcu

BOX 2
Siliciclastic non-carbonate
Heteroithic flaser and Linsen Bedding
Quartz veins
Bedding 60-70.
Cleavage close to bedding

BOX 3
Siliciclastic non-carbonate
Heterolithic wavy bedding in upper half
Grey mudstone and siltstone in lower half.
Bedding/Cleavage c. 80.

BH06-EC
BOX 16
37.10-38.7m
Siliciclastic non-carbonate
Heterolithic linsen, wavy and flaser bedding
KNcu

BOX 17
38.70- 40.2m
Siliciclastic non-carbonate
Heterolithic wavy bedding
Bedding 80.
20cm weakly calcareous zone that would not be classified as a limestone
?due to late fluid migration along cleavage
KNcu

BOX 18
40.20- 41.70m
Siliciclastic non-carbonate
Heterolithic 60-70% mudstone
Bedding c.80
Cleavage ?parallel
bedding
KNcu

BOX 19
41.70- 44.70m
Siliciclastic non-carbonate
Heterolithic mudstone dominant linsen (upper 50cm)
Remainder of section sandstone dominant flaser (<20% mudstone) levels
Bedding c.80
KNcu

BOX 20
44.70- 46.20m
Siliciclastic non-carbonate
Heterolithic sandstone dominant flaser <20% mudstone

Bedding c.80
Joint 75
KNcu

BOX 21
46.20- 47.70m
Siliciclastic non-carbonate
Heterolithic sandstone dominant flaser <20% mudstone
Bedding c.85
Cleavage ?parallel bedding
?Fault dip 82
Quartz vein along fault

BOX 22
47.70- 49.20m
Siliciclastic non-carbonate
Heterolithic sandstone dominant flaser <20% mudstone
Bedding c.80
Cleavage 85

BOX 23
49.20m- 50.70m
Siliciclastic non-carbonate
Heterolithic sandstone dominant flaser <20% mudstone
Heterolithic <80% mudstone/siltstone
Bedding c.80
Cleavage 85
KNcu

One 25cm long vein about 1mm thick composed ofa calcareous crystalline mineral.
The vein occurs as a joint infilling. This is the product of a late stage fluid migration along the joint and is not part of the original lithified sediment. Two other intersecting carbonate filled joints.

BH08-EC
BOX 1
16.70-18.35m
Siliciclastic non-carbonate
Heterolithic mudstone dominant linsen
Bedding c.30
Cleavage 85+
Lineation L1 10
KNcu

BOX 2
18.35m- 19.85m
Siliciclastic non-carbonate
Heterolithic mudstone dominant linsen 80% dark grey mudstone
Thin silty sandy streaks
Bedding <20
Cleavage 90
KNCu/pc

BOX 3
19.85-21.50m
Siliciclastic non-carbonate
Heterolithic mudstone dominant linsen <90% mudstone
Bedding c.10
Cleavage 90

BOX 4
21.50-23.15m
Siliciclastic non-carbonate
Heterolithic mudstone dominant linsen
<90% mudstone
Bedding c.10
Cleavage 90

BOX 9
29.80m-31.40m
Siliciclastic non-carbonate
Mudstone/siltstone dominant
c.5% sandstone
<0.1% calcareous
Bedding c.20

Cleavage ?85-90
KN

BOX 10
31.40m-32.91m
Siliciclastic non-carbonate
Heterolithic flaser
65% sandstone
Bedding c.25
Cleavage 65
KNcu

BOX 11
32.90m- 34.40m
Siliciclastic non-carbonate
Heterolithic linsen
20% sandstone
Bedding c.30
Joint 70
KNcu/pc

BOX 12
34.40- 35.95m
Siliciclastic non-carbonate
Heterolithic linsen
20% sandstone
Bedding c.25
Cleavage 90
KNcu/pc

BOX 13
35.95m- 36.50m
Siliciclastic non-carbonate
Heterolithic linsen
20-30% sandstone
Sandstone lenses dragged into cleavage
Bedding c.25-30
Cleavage 62
Three joints 77-80
KNcu/pc

BOX 14
36.50- 37.65m
Siliciclastic non-carbonate
Heterolithic linsen
10% silt laminations
90% mudstone
Bedding 45
Cleavage 90
Joint 77
KNcu/pc

BOX 15
37.65- 39.35m
Siliciclastic non-carbonate
Heterolithic linsen
Locally flaser
Bedding 35
Cleavage 65
KNcu/pc

BOX 16
39.35- 41m
Siliciclastic non-carbonate
Flaser up to 70% sand and silt
Bedding 45-55 disrupted by cleavage
Cleavage 65
KNcu/pc

BOX 17
41- 42.65m
Siliciclastic non-carbonate
Medium to dark grey mudstone
Local coarser silty and fine sand levels

Localised thin (<1mm) calcareous
infilling to veins along steep ?joints(65-70)
Cleavage 66
Beds appear to be dragged into cleavage
KN

Appendix A4. Strike and dip directions of discontinuities at onshore outcrops
Orientations shown consist of two numbers followed by a letter code, e.g. 122-70w. The first number refers to the strike or orientation of contour lines on the discontinuity. It is shown in degrees from True North. The second number is the Dip or angle of inclination of the discontinuity and is given in degrees from the horizontal. The letter code is the general direction to which the planes are inclined.

RINGACOLTIG NORTH
Joints
132-78sw master joint
155-85sw master joint
138-70sw bending to 150-85w master joint
144-80sw
192-50e
192-75e
144-75sw
135-82sw
135-85ne
128-72ne
116-75sw

Bedding
073-70se
070-80se
Locally undulating due to folding

Cleavage
060-82nw
064-85nw
064-82nw

RINGACOLTIG SOUTH
Joints
163-80sw
187-85e
160-85se
190-85e

Fracture cleavage
074-80se

RAILWAY SECTION-Rushbrook Railway Station
Joints
172-64e
002-70e
170-65e
180-80e-90

Bedding
068-50se

c.070-70e

Cleavage
066-85se
074-85se
070-85nw
066-90

Faults
c.080-c.60s

MONKSTOWN NORTH (Ballytrasna Formation)
Joints
164-86ne

Bedding
c.070-60se

Cleavage
073-82 to 90

MONKSTOWN SOUTH (Gyleen Formation Monkstown Glen Road)
Joints
136-88sw
166-84w
146-88sw
350-80e
344-88w
337-85e
005-58e
070-58n
012-70n
152-70n
176-88e

Bedding
c.070-70se
c.083-42s
c.075-50s

Cleavage
074-80s
069-80s

MONKSTOWN COASTAL
Joints
357-90
348-80w
028-85s
360-90

004-70w

Bedding
066-85s
092-70s
076-85n
074-80n
070-45s
075-80s
068-65s
076-70s

Appendix A5. Logs of joint spacing at Ringacoltig

East to west log parallel to bedding strike of spacing between joints in millimetres.

The symbol / represents a joint.

Ringacoltig North

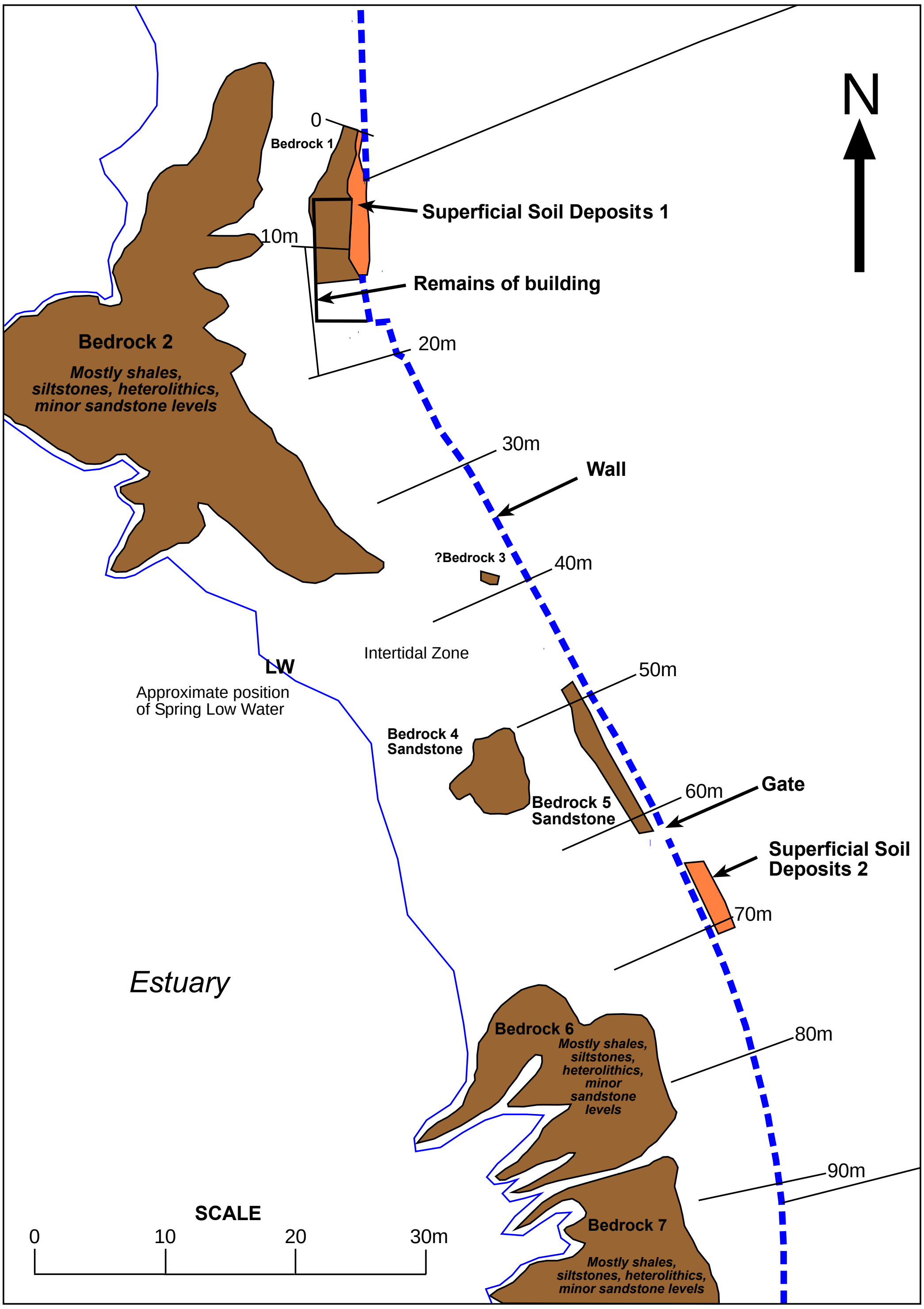
40 / 30 / 40 / 50 / 200 / 640 / 800 /(master joint) 50 / 70 / 4 / 100 / 560 / (master joint) 190 / 140 / 770 / 280 / 120 / 50 / 90 / 90 / 440 / 190 / 100 / 120 / 90 / 60 (exposure gap) 500 / 400 / 80/ 4000+

Ringacoltig South

180 / 50 / 300 / 340 / 330 / 290 / 220 / 270 / 80 / 40 / 70 / 370 / 170 / 80

Appendix A6. Map and photographs of the exposed bedrock at Ringacoltig coastal zone

Photo A6/1a. Aerial view of Ringacoltig coastal zone showing approximate areas of bedrock outcrop outlined in white line. Strike of bedding/cleavage shown in red. Image *Google Earth*.



Map A6/1b. Map showing bedrock outcrops along the Ringacoltig coastal zone.

Photo A6/2. Bedrock 1. c.0-20m. Superficial deposits resting on the bedrock which is Composed of fine-grained heterolithic rocks with intense fracture cleavage fabric. Red line shows outline of ruined house foundations.

Photo A6/3. Bedrock 1- c.0-5m. Superficial soil deposits resting on strongly cleaved mudstones and heterolithic rocks.

Photo A6/4. Bedrock 5. 50-60m Undulating beds in sandstones of the Cuskinny Member.
The beds are extensively fractured by a vertical fracture cleavage and intense jointing.

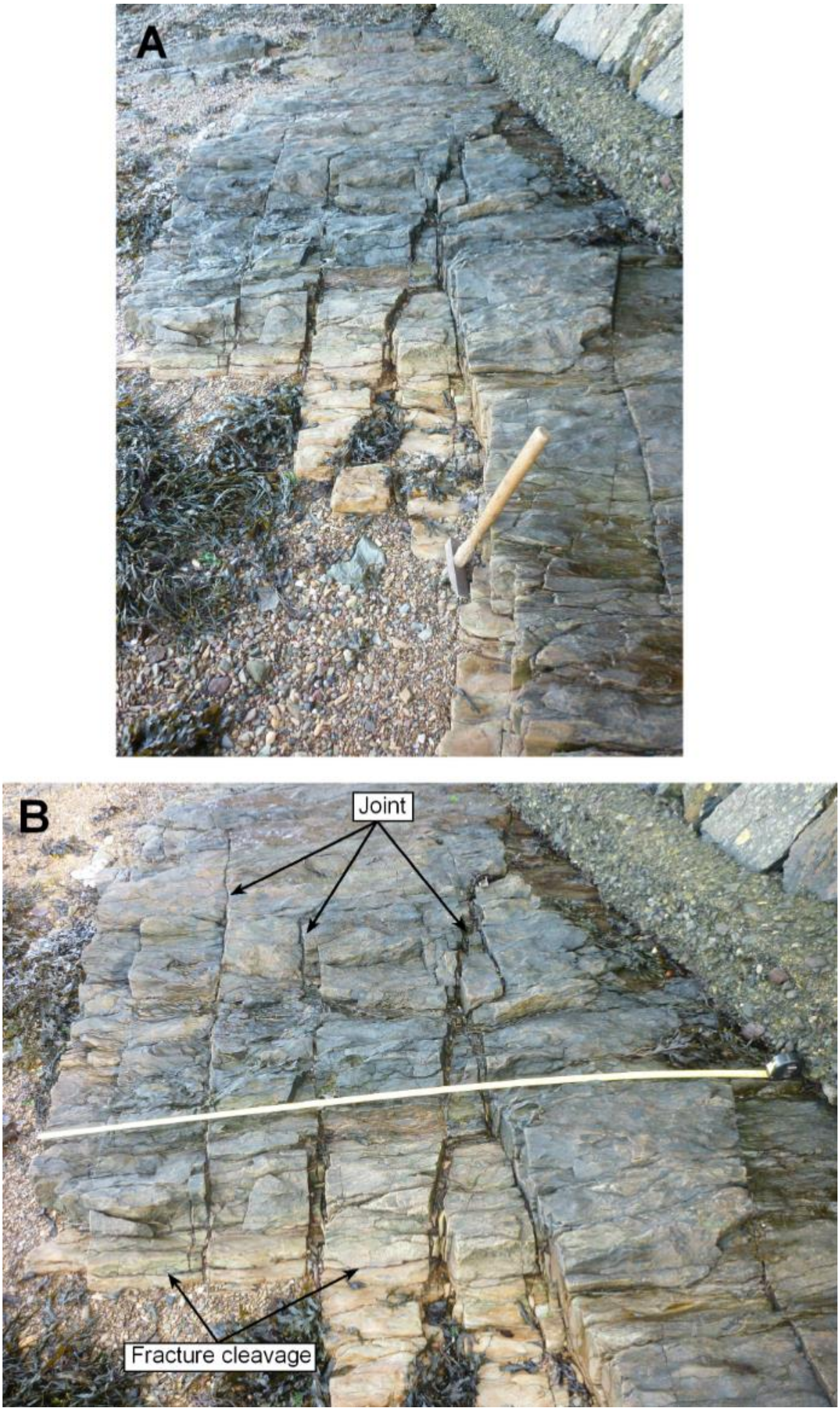


Photo A6/5. Bedrock 5. C.55m. Vertical north-south orientated joints in fractured sandstones. The fabric parallel to the tape is a fracture cleavage. Scale 1m.


Photo A6/6. Bedrock 1. C.5m. Two sets of intersecting joints in cleaved heterolithics bedrock. Scale 1m.

Photo A6/7. Intersecting joint sets in fractured sandstones of the Cuskinny Member at Ringacoltic shore north. The fractures parallel to the hammer shaft are a fracture cleavage. This is a widely spaced cleavage that persists through sandstones. Note that some of the joints are laterally discontinuous. The top surface of the bedrock here is a bedding plane.

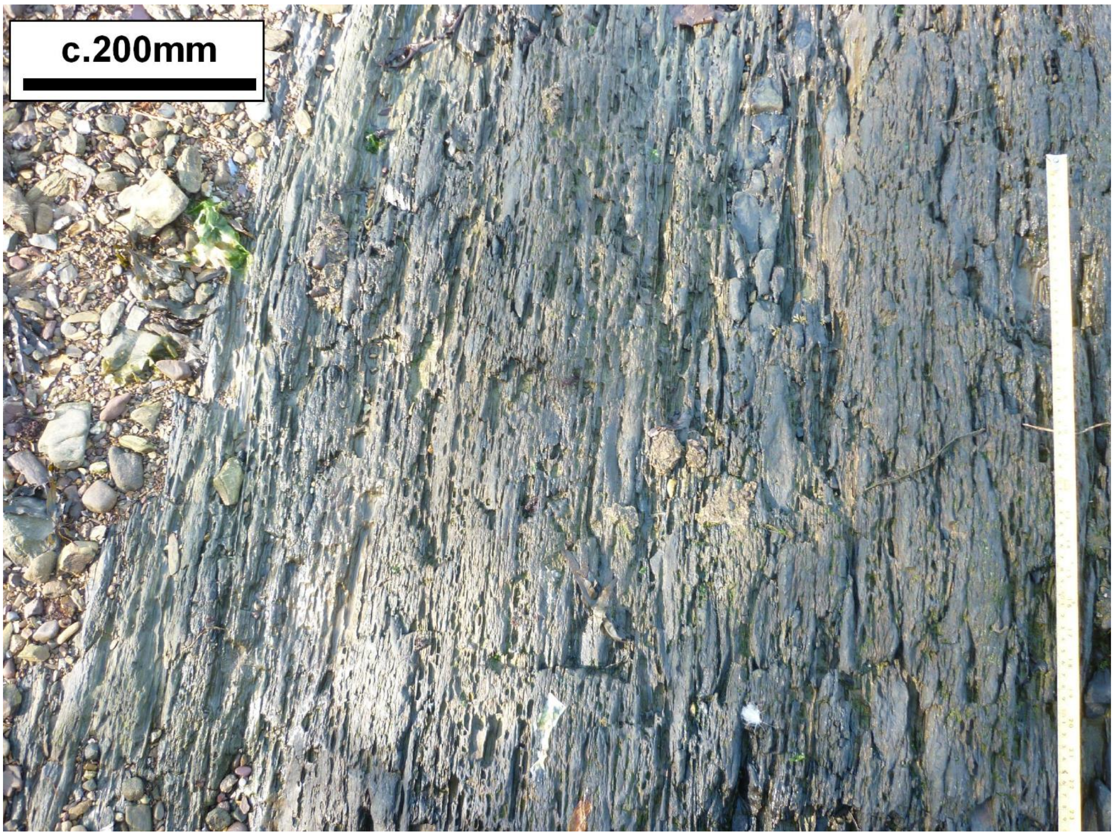


Photo A6/8. Cleaved mudstones and heterolithics at Ringacoltig north. Cleavage planes are parallel to the tape and are closely spaced and inclined steeply to the north (left).

Appendix A7. Photographs of the Rushbrooke railway section

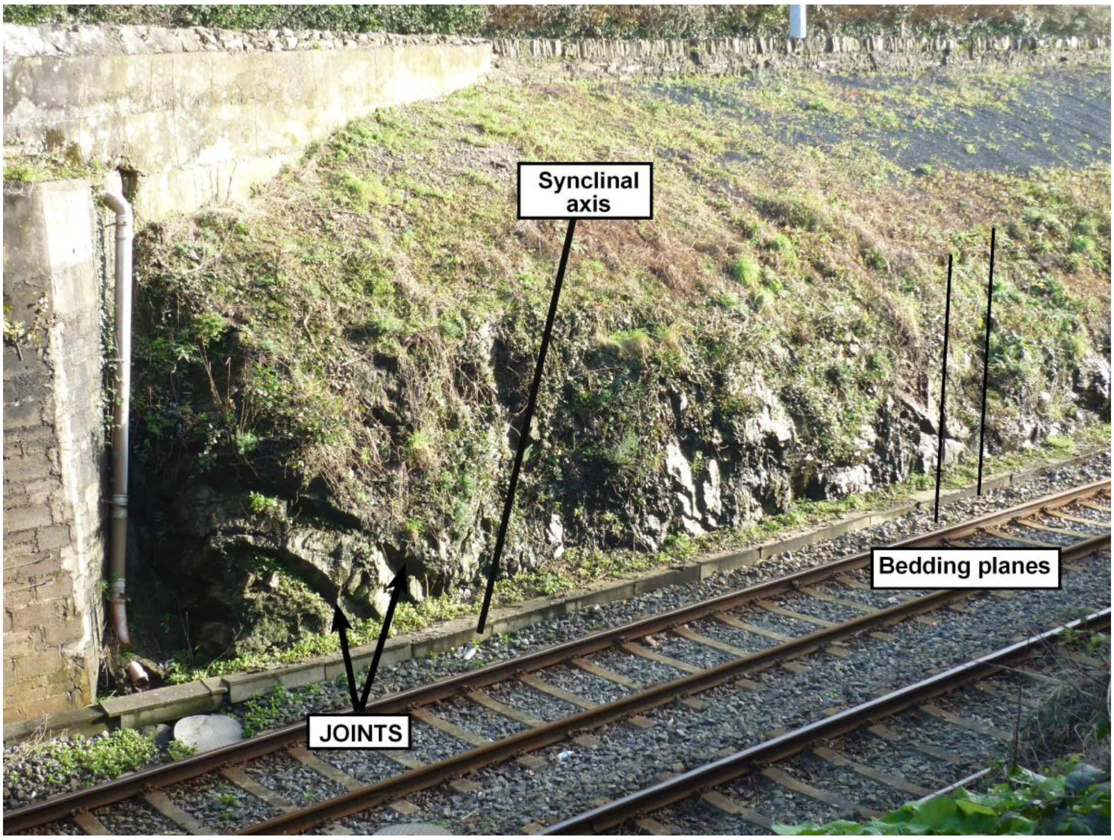


Photo A7/1. View eastwards of Syncline 1 axis exposed on the eastern side of Bridge 1.

Photo A7/2. View westward of the railway section on the eastern side of Bridge 2. The bedding dip is towards the left (i.e. to the south-southeast).

Photo A7/3. General view south-southeastwards taken from Bridge 3 towards Bridge 4 showing the outcrop of the Cuskinny Member which shows extensive closely-spaced jointing here.

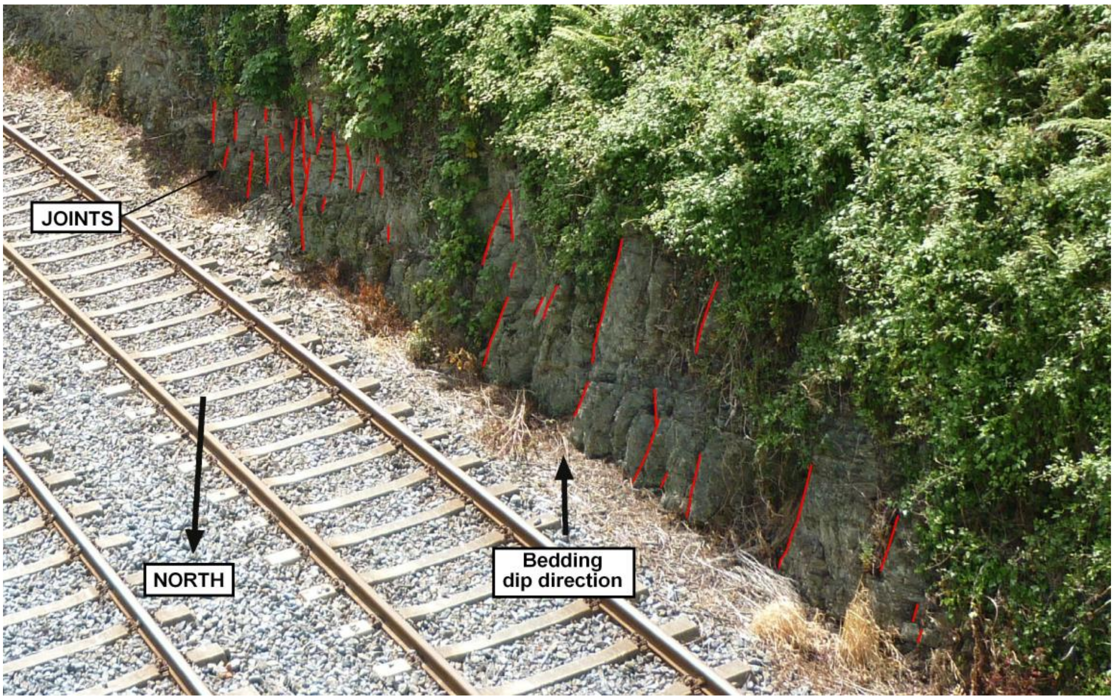


Photo A7/4. Detailed view southwards of part of the railway section between Bridge 3 and Bridge 4. The joints (red lines) are vertical to sub-vertical and strike roughly north-south. More than one set of joints is present here and their spacing is variable.

Photo A7/5. This is a view looking northwestwards from Bridge 4 towards Bridge 3. Blue lines show the general development of the cleavage fabric here. The fabric is vertical to sub-vertical and is oriented NE-SW. This is typical of these rocks in the region.

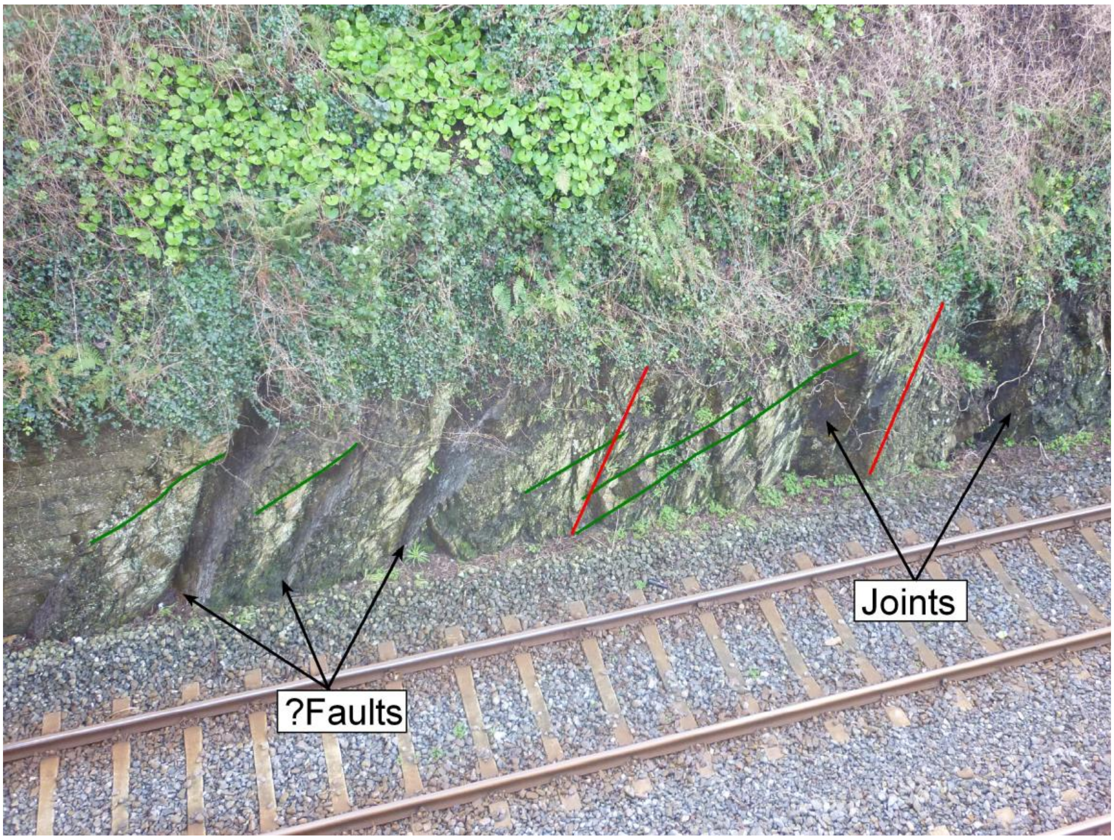


Photo A7/6. Cleavage (red) and bedding (green) planes in the Cuskinny Member on the western side of Bridge 4 (view south-westwards).

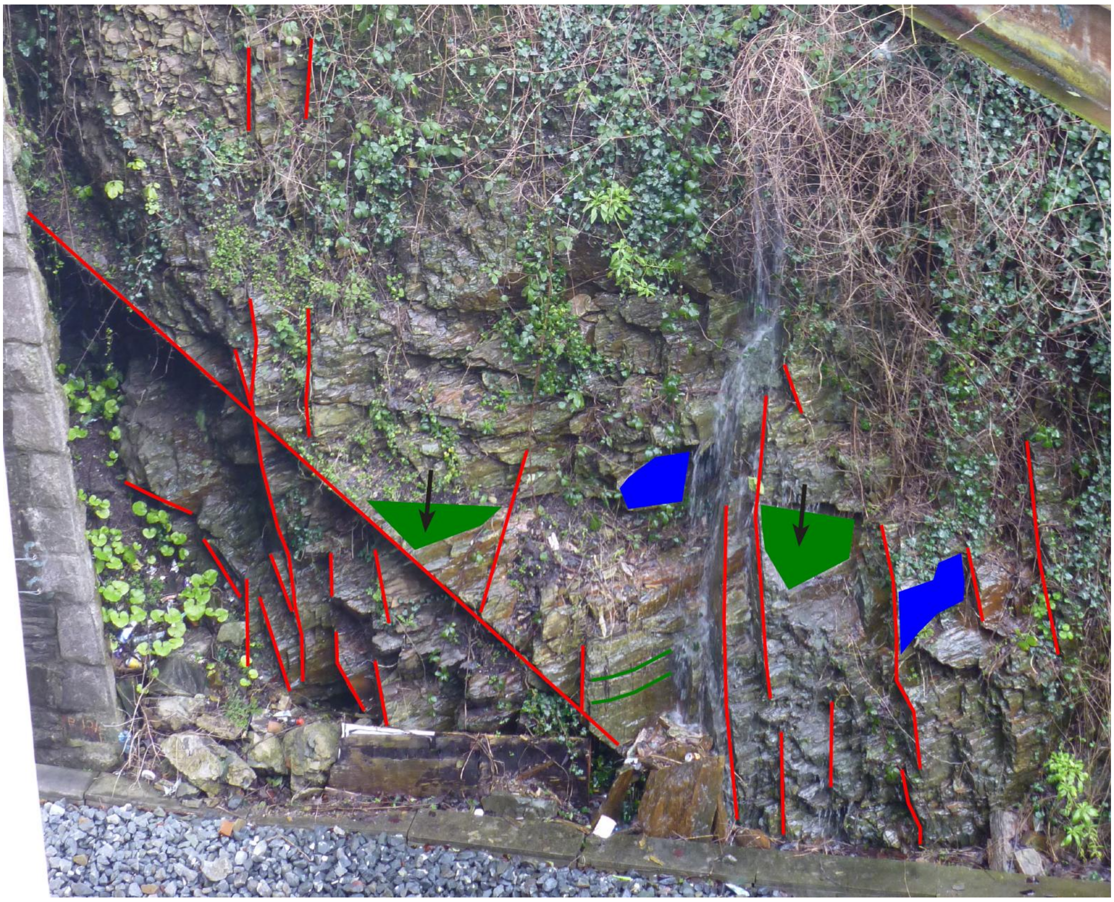


Photo A7/7a. Jointing (red), bedding planes (green) and cleavage planes (blue) in the Cuskinny Member on the eastern side of Bridge 4 looking northwards.

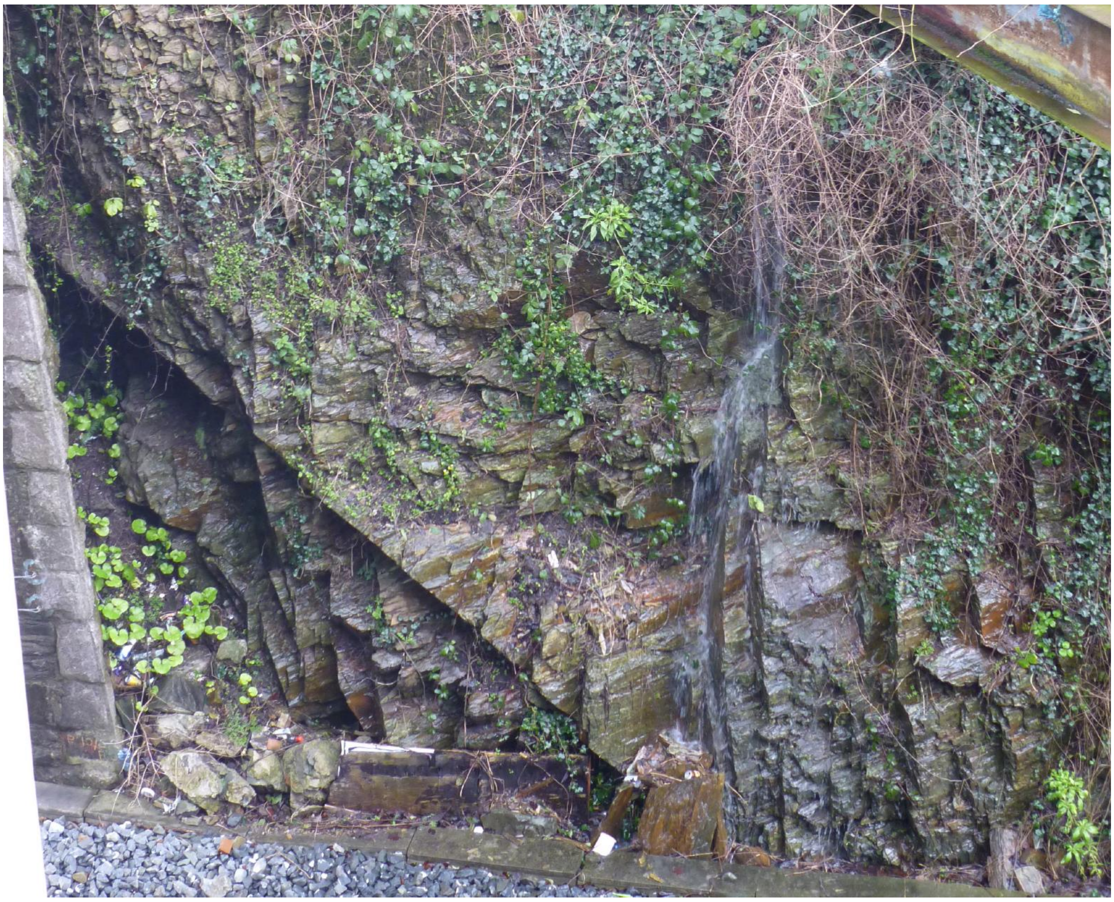


Photo A7/7b. This shows the same image as Photo A7/7a but without annotation.

Photo A7/8. Jointing (parallel to the red line) and bedding (parallel to the green line) in the Cuskinny Member on the eastern side of Bridge 4 looking southwards.

Appendix A8. Petrographical analyses from offshore boreholes

Lithology

The bedrock is composed almost entirely of siliciclastic non-carbonate (i.e. non-limestone) sedimentary rock. These comprise claystones, siltstones, sandstones and heterolithics (intricately interlaminated sandstone/mudstone). There may also be thick (possibly up to about 10m) relatively uniform mudstone units within the succession. All of these rocks have endured low-grade metamorphism characterised by the development of a slatey cleavage.

Petrography and mineralogical composition

Detailed petrographical analyses have been carried out by *Conodate Geology* on Boreholes BH04-EC to BH09-EC. This report is contained in *Causeway Geotechnical Report 13-381 Factual*. The *Conodate* report provides an important detailed analysis of the mineralogical composition of selected bedrock samples, the findings of which may have a significant bearing on the drilling procedures adopted. The report should be viewed in conjunction with this report.

An important component of the bedrock is the mineral Quartz. This accounts for 57-84% in sandstones and 20% in mudstones.

Apart from one of these analyses, the bedrock is within the Cuskinny Member. The compositions described here from the Cuskinny Member would be likely to be broadly similar to those in the same member along the route.

The results of the Conodate petrographical analysis are summarised below.

The information is given as; Mineral/Volume % /Crystal or Grain size mm/ Origin

BH04-EC 30m - Kinsale Formation Cuskinny Member
Sandstone
Quartz 68% 0.1-0.4mm Primary
Clay Mineral 20% <0.01mm Primary / Secondary
Mud 10% <0.01mm Primary
Muscovite <0.5% 0.2-0.4mm Primary
Pyrite <0.5% <0.1-0.3mm Primary
Ilmenite <0.5% <0.1mm Primary
Zircon <0.1% 0.3mm Primary

BH05-EC 22.4m - Kinsale Formation Cuskinny Member
Heterolithic Sandstone dominant
Quartz 58% 0.1-0.3mm Primary
Clay Mineral 30% <0.01mm Primary / Secondary
Feldspar 7.0% 0.1-0.2mm Primary
Mud 3.0% <0.01mm Primary
Muscovite 1.0% 0.1-0.4mm Primary
Pyrite <0.5% <0.1mm Primary
Ilmenite <0.5% <0.2mm Primary
Zircon <0.1% <0.1mm Primary

BH05-EC 44.6m- Kinsale Formation Cuskinny Member
Heterolithic Sandstone 60%, Mudstone 40%
Quartz 55% 0.1-0.3mm Primary
Clay Mineral 35% <0.01-0.3mm Primary / Secondary
Feldspar 3.0% 0.1-0.2mm Primary
Mud 3.0% <0.01mm Primary

Muscovite 2.0% 0.1-0.3mm Primary
Zircon 0.5% <0.1-0.3mm Primary
Pyrite 0.5% <0.1mm Primary
Ilmenite <0.5% 0.2mm Primary

BH06-EC 28m- Kinsale Formation ?Castle Slate Member/Cuskinny Member
Mudstone/siltstone/fine sandstone
Quartz 57% <0.1-0.2mm Primary
Clay Mineral 35% <0.01-0.2mm Primary / Secondary
Mud 5.0% <0.01mm Primary
Muscovite 2.0% 0.1-0.2mm Primary
Pyrite 1.0% <0.1-0.2mm Primary

BH08-EC 25m- Kinsale Formation Cuskinny Member
Mudstone
Clay Mineral 76% <0.01mm Primary
Quartz 20% <0.05mm Primary
Muscovite 3.0% <0.1mm Primary
Pyrite <0.1% <0.01mm Primary
Ilmenite <0.5% <0.1mm Primary
Hæmatite <0.1% <0.1mm Secondary

BH09-EC 43m- Kinsale Formation Cuskinny Member
Sandstone
Quartz 84% 0.1-0.5mm Primary
Clay Mineral 10% <0.01-0.3mm Primary / Secondary
Feldspar 5.0% 0.2-0.4mm Primary
Muscovite <0.5% 0.1-0.6mm Primary
Ilmenite <0.5% <0.1mm Primary
Hæmatite <0.5% <0.2mm Primary / also weathered

Detailed descriptions of BH04-EC, BH05-EC, BH08-EC and BH09-EC

BH 04-EC, 30.00m

Source	Causeway Geotech Sample	
Condition	Dry core fragment	Weight 2,250gm
Appearance	Clean, fresh core fragment, trace iron oxidation (weathering) noted along fractures.	

HAND SPECIMEN

Appearance	Mid to dark grey, medium-grained, poorly to moderately-sorted heterolithic rock with mid-grey sandstone (90%) and black mudrock wisps (10%).
Joints / fractures	None visible.
Veins	One quartz vein noted, 1-3mm in width.
Texture	Sedimentary, convolute bedding / lamination.
Porosity	Moderate intergranular porosity, <1.0%.
Strength	Medium-strong to strong.

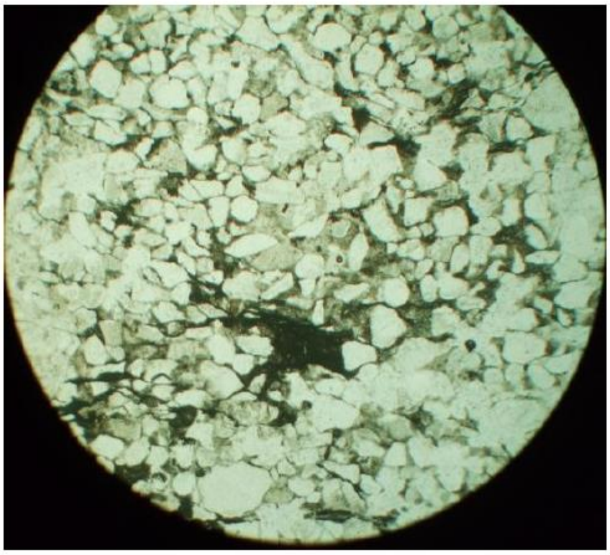
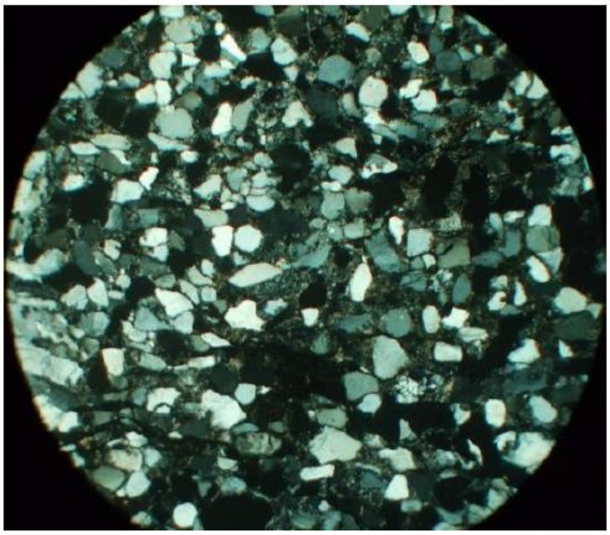
THIN SECTION

COMPONENT	PETROGRAPHY
Structure	This is a medium-grained, moderately- to well sorted, sandstone. The components present are quartz, clay mineral, mud intraclasts and muscovite. The matrix is composed of fine-grained clay mineral and thin lenses / stringers of mud. There is a 1mm quartz vein present. The texture of the rock exhibits convolute bedding (folded / distorted bedding). **LITHIC WACKE**
Quartz	Occurs as sub-rounded grains, grains occasionally contain minor fractures, strain shadowing is visible, present as monocrystalline and polycrystalline grains.
Clay Mineral	Occurs as fine-grained material in the matrix and as occasional rounded grain.
Mud	Occurs as sub-angular intraclasts and stringers, present as very fine-grained opaque material.
Muscovite	Minor occurrence as elongate grains.
Pyrite	Minor occurrence in mudrock stringer and intraclasts, occasionally occurs as medium-grained cubic grains.
Ilmenite	Minor occurrence as sub-rounded grains.
Zircon	Trace occurrence as rounded grain.

COMPONENTS	Volume %	Crystal / Grain size	Origin
Quartz	68%	0.1-0.4mm	Primary
Clay Mineral	20%	<0.01mm	Primary / Secondary
Mud	10%	<0.01mm	Primary
Muscovite	<0.5%	0.2-0.4mm	Primary
Pyrite	<0.5%	<0.1-0.3mm	Primary
Ilmenite	<0.5%	<0.1mm	Primary
Zircon	<0.1%	0.3mm	Primary

DIAGNOSIS:

GREY SANDSTONE

	**BH 04-EC, 30.00m** Hand specimen cm scale Medium-grained, grey sandstone and dark grey mudrock wisps Bioturbated texture 1-3mm quartz vein visible in core e.g. running top right to centre left on far left sample
	Plane Polarised Light. Field of view: 3mm Medium-grained, moderately-sorted sandstone with mudrock intraclasts (e.g. bottom centre). Matrix is composed of clay mineral (e.g. light brown area – centre right)
	Crossed polarised light. Sub-rounded quartz grains (grey grains)

I. A. J MacCarthy
8th July *2016*

BH 05-EC, 22.40m

Source	Causeway Geotech Sample
Condition	Damp core. Weight 1,250gm
Appearance	Clean, fresh core sample, core diameter 10.2cm, iron oxidation staining noted on core end.

HAND SPECIMEN

Appearance	Cream to dark grey, heterolithic rock with cream, medium-grained, moderately well sorted sandstone (75%) and dark grey, fine-grained mudrock (25%), pyrite flakes are noted in mudrock laminations.
Joints / fractures	Minor fracture, <0.5mm, present along sandstone / mudrock contacts.
Veins	None visible.
Texture	Sedimentary, flaser bedding and lineation visible.
Porosity	Minor intergranular and fracture porosity present.
Strength	Medium-strong to strong.

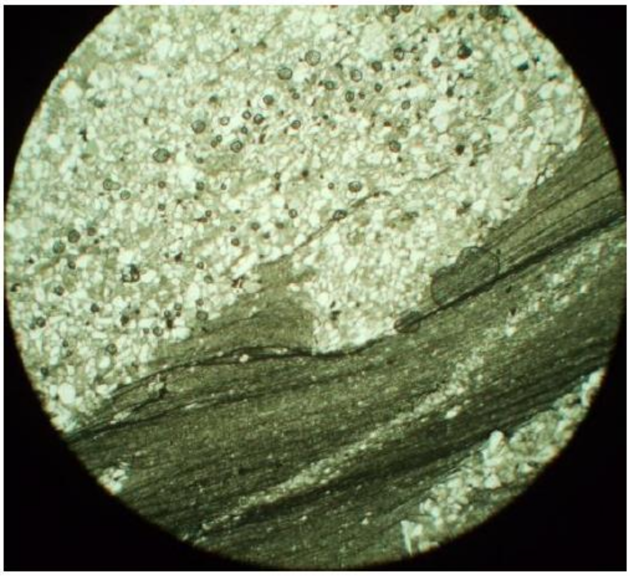
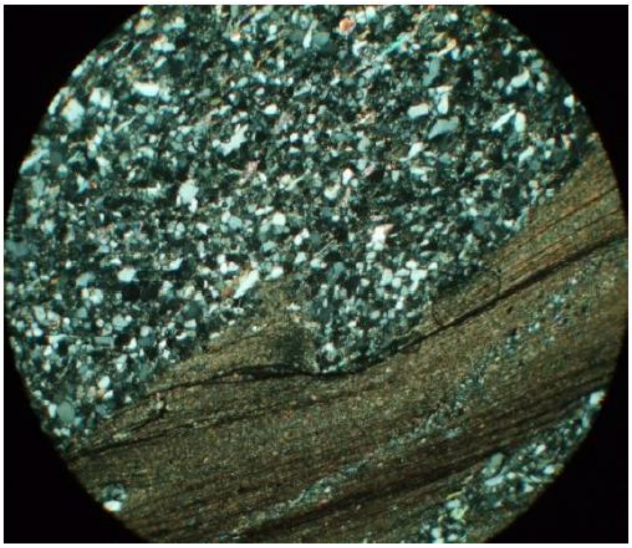
THIN SECTION

COMPONENT	PETROGRAPHY
Structure	This is a fine to medium-grained, moderately-sorted rock sample with interbedded well-sorted sandstone and cross-bedded mudrock. The rock has a flaser-bedded texture. The matrix is composed of clay mineral, possibly smectite, and fine-grained quartz. The components in the sample are quartz, muscovite, clay mineral, zircon, feldspar, opaques, and mud. **FLASER-BEDDED SANDSTONE AND MUDROCK**
Quartz	Occurs as sub-rounded to sub-angular grains and fine grains in the matrix.
Clay Mineral	Occurs as fine-grained material, dominantly present in mudrock, also occurs in matrix of sandstone units.
Feldspar	Occurs as sub-rounded grains, appear moderately fresh.
Mud	Occurs as very fine-grained, opaque stingers in clay lenses / mudrock layers.
Muscovite	Occurs as elongate detrital grains.
Pyrite	Occurs as fine grains in mudrock, occasional cubic grains.
Ilmenite	Occurs as sub-angular grains.
Zircon	Trace occurrence in sandstone as rounded detrital grain.

COMPONENTS	Volume %	Crystal / Grain size	Origin
Quartz	58%	0.1-0.3mm	Primary
Clay Mineral	30%	<0.01mm	Primary / Secondary
Feldspar	7.0%	0.1-0.2mm	Primary
Mud	3.0%	<0.01mm	Primary
Muscovite	1.0%	0.1-0.4mm	Primary
Pyrite	<0.5%	<0.1mm	Primary
Ilmenite	<0.5%	<0.2mm	Primary
Zircon	<0.1%	<0.1mm	Primary

DIAGNOSIS:

GREY FLASER-BEDDED SANDSTONE AND MUDROCK

	**BH 05-EC, 22.40m** Hand specimen cm scale Flaser-bedded light grey sandstone and dark grey mudrock
	Plane Polarised Light. Field of view: 3mm Fine, moderately sorted sandstone with mudrock layer running centre right to bottom left
	Crossed polarised light. Mudrock layer is composed of clay mineral (brown, fine-grained material – bottom right) with mud (opaque) stringers highlighting cross-bedding.

BH 05-EC, 44.60m

Source	Causeway Geotech Sample	
Condition	Damp core	Weight 1,150gm
Appearance	Clean, fresh core, core diameter 10.2cm.	

HAND SPECIMEN

Appearance	Mid-grey, heterolithic rock sample with laminated intervals of dark grey, well-sorted mudrock (60%) and mid-grey, medium-grained sandstone (40%).
Joints / fractures	Thin fractures present along lineation (crosscuts bedding), <0.5mm in width, occasionally partially-infilled with quartz.
Veins	None visible apart from partially infilled fractures.
Texture	Sedimentary, medium to thick, discontinuous laminations (2-10mm), stain lineation highlighted by thin fractures crosscuts bedding at 40°.
Porosity	Minor porosity along fractures.
Strength	Medium-strong to strong.

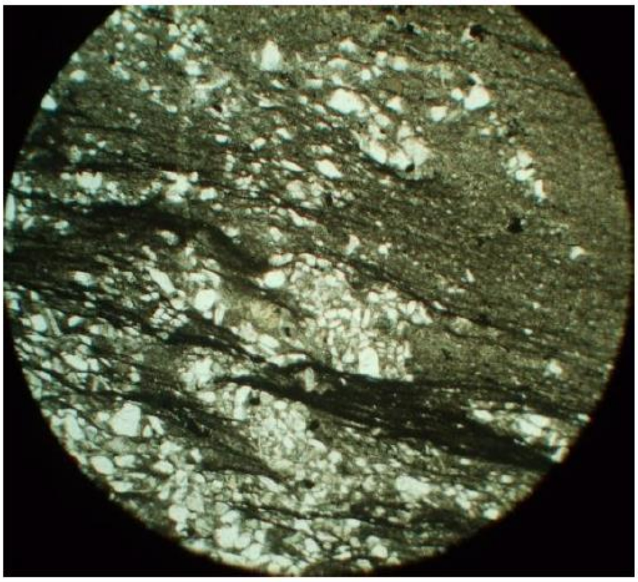
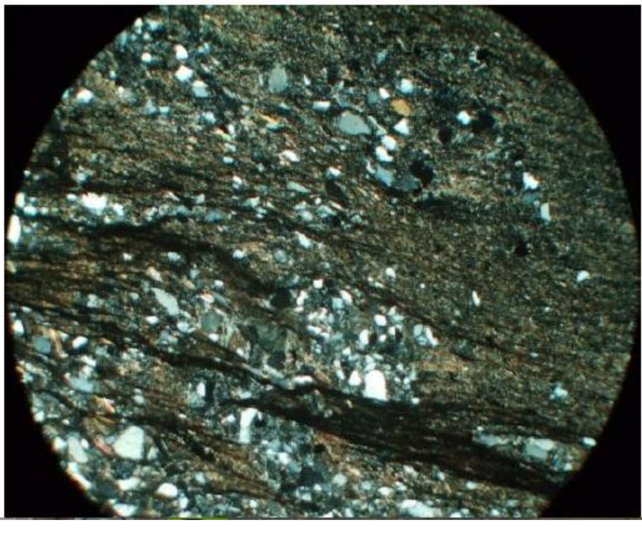
THIN SECTION

COMPONENT	PETROGRAPHY
Structure	This is a fine to medium-grained, moderately-sorted rock sample with flaser-bedded well-sorted sandstone and cross-bedded mudrock. The matrix is composed of clay mineral and fine-grained quartz. The components in the sample are quartz, feldspar, muscovite, clay mineral, zircon, mud and opaques.
	FLASER-BEDDED SANDSTONE AND MUDROCK
Quartz	Occurs as sub-rounded to sub-angular grains and fine grains in the matrix.
Clay Mineral	Occurs as fine-grained material in the matrix of the sandstone and as dominant component in mudrock layers, occasional occurrence of chloritic grains.
Feldspar	Minor occurrence as sub-rounded grains.
Mud	Occurs as very fine-grained, opaque material, defines cross-bedding in mudrock layers.
Muscovite	Occurs as elongate detrital grains.
Zircon	Minor occurrence in sandstone as rounded detrital grains.
Pyrite	Minor occurrence of pyrite specks in mudrock.
Ilmenite	Trace occurrence of sub-rounded grains.

COMPONENTS	Volume %	Crystal / Grain size	Origin
Quartz	55%	0.1-0.3mm	Primary
Clay Mineral	35%	<0.01-0.3mm	Primary / Secondary
Feldspar	3.0%	0.1-0.2mm	Primary
Mud	3.0%	<0.01mm	Primary
Muscovite	2.0%	0.1-0.3mm	Primary
Zircon	0.5%	<0.1-0.3mm	Primary
Pyrite	0.5%	<0.1mm	Primary
Ilmenite	<0.5%	0.2mm	Primary

DIAGNOSIS:

GREY FLASER-BEDDED SANDSTONE AND MUDROCK

	**BH 05-EC, 44.60m** Hand specimen cm scale Grey, heterolithic rock with dark grey mudrock layers and light grey sandstone layers
	Plane Polarised Light. Field of view: 3mm Heterolithic, flaser-bedded texture with fine-grained mudrock layers (top right) interbedded with medium-grained sandstone layers (bottom left)
	Crossed polarised light. Bedding lineation is running top left to bottom right Mud stringers (opaque material – e.g. bottom right)

BH 08-EC, 25.00m

Source	Causeway Geotech Sample
Condition	Damp core fragment Weight 1,275gm
Appearance	Moderately clean, fresh core fragment, trace amount of weathering noted along fracture surfaces.

HAND SPECIMEN

Appearance	Mid grey / green, fine-grained, moderately to well-sorted, thinly laminated siltstone and mudrock.
Joints / fractures	Thin fractures, <0.5mm present, crosscut laminations at approx. 90˚.
Veins	None present.
Texture	Sedimentary, thinly laminated.
Porosity	Minor fracture and intergranular porosity.
Strength	Weak to medium-strong.

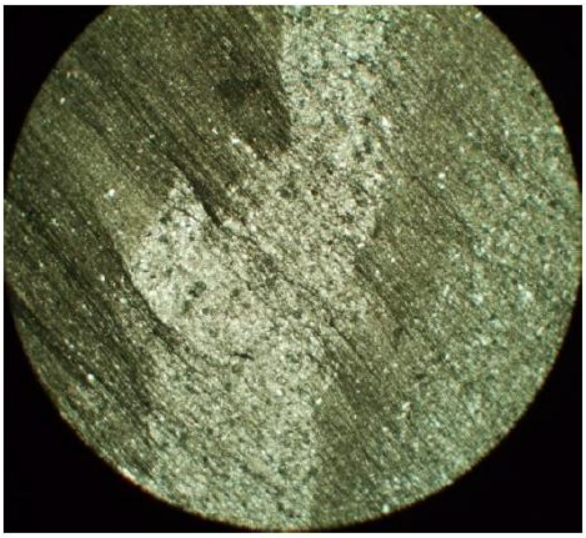
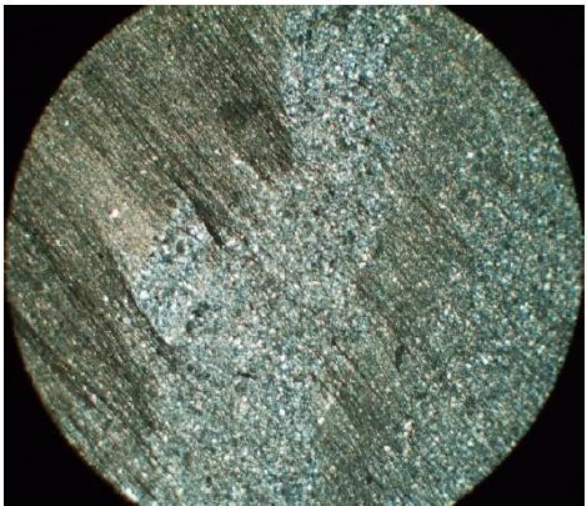
THIN SECTION

COMPONENT	PETROGRAPHY
Structure	This is a fine-grained, well-sorted, thinly laminated mudrock with silty mudrock units. The laminations are 0.2-3mm in width. The matrix of the rock is composed of fine-grained clay mineral and quartz. The components in the rock are clay mineral, quartz, muscovite, and opaques. There are thin stylolites present running perpendicular to the lamination. There is a thin fracture running parallel to the lamination with hæmatite weathering visible on either side of the fracture. **LAMINATED MUDROCK**
Clay Mineral	Occurs as fine-grained material throughout.
Quartz	Occurs as silt-sized grains, concentrated in silty mudrock laminations.
Muscovite	Minor occurrence as elongate detrital grains, occur along lamination lineation.
Opaques	Consists of specks of pyrite and ilmenite, fine-grained hæmatite occurs along fracture.

COMPONENTS	Volume %	Crystal / Grain size	Origin
Clay Mineral	76%	<0.01mm	Primary
Quartz	20%	<0.05mm	Primary
Muscovite	3.0%	<0.1mm	Primary
Pyrite	<0.1%	<0.01mm	Primary
Ilmenite	<0.5%	<0.1mm	Primary
Hæmatite	<0.1%	<0.1mm	Secondary

DIAGNOSIS:

GREY LAMINATED MUDROCK

	**BH 08-EC, 25.00m** Hand specimen cm scale Mid-grey, fine-grained, thinly laminated mudrock Laminations are visible running top to bottom on core (top) and cut (bottom) surfaces
	Plane Polarised Light. Field of view: 3mm Fine-grained, well-sorted mudrock (left) and silty mudrock (centre) layers.
	Crossed polarised light. Laminated texture is running top right to bottom left

BH 09-EC, 43.00m

Source	Causeway Geotech Sample
Condition	Damp core fragment Weight 1,300gm
Appearance	Clean, slightly weathered sample, iron oxidation weathering noted along fractures and vuggy vein surfaces.

HAND SPECIMEN

Appearance	Light grey, medium-grained, well-sorted, non-calcareous sandstone.
Joints / fractures	Thin fracture <0.5mm in width.
Veins	Quartz veins <1cm in width are present.
Texture	Sedimentary, massive texture, slightly vuggy texture possibly due to some dissolution.
Porosity	Moderate porosity <1.0%.
Strength	Strong to very strong.

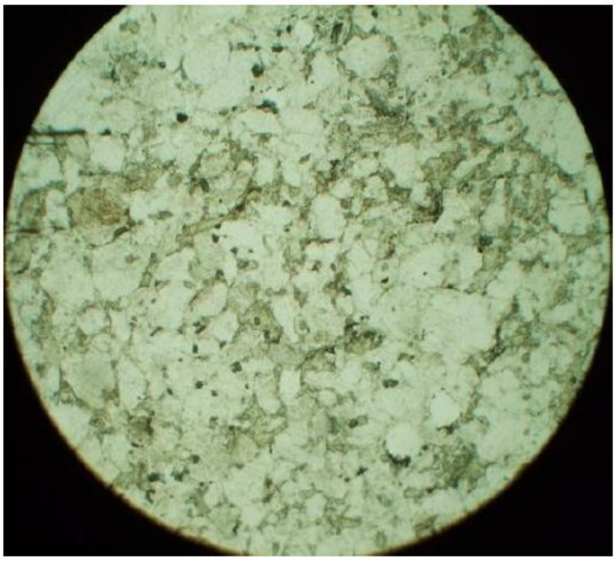
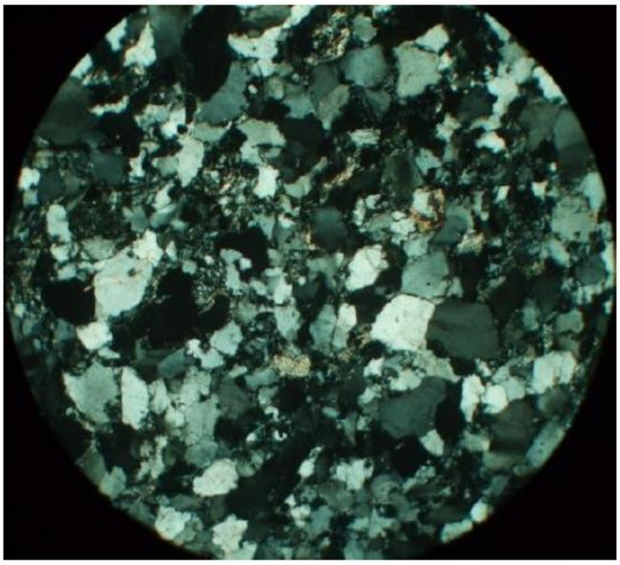
THIN SECTION

COMPONENT	PETROGRAPHY
Structure	This is a medium-grained, well-sorted, sandstone. The components present are quartz, feldspar, and clay mineral. The grain contacts are solutional. There is a thin fracture present (<0.1mm) with weathered hæmatite visible on either side of the fracture. There is a thin 0.5mm quartz vein present. **QUARTZ ARENITE**
Quartz	Occurs as subhedral grains, grains contain minor fractures, exhibit strong strain-shadowing, present as monocrystalline and polycrystalline grains.
Clay Mineral	Minor occurrence as rounded grains, alteration product in feldspar grains and medium-grained, chlorite grains.
Feldspar	Occurs as subhedral grains, exhibits minor to moderate alteration to clay mineral.
Muscovite	Minor occurrence as elongate grains.
Ilmenite	Trace occurrence as sub-rounded grains.
Hæmatite	Occurs as weathered grains close to fracture.

COMPONENTS	Volume %	Crystal / Grain size	Origin
Quartz	84%	0.1-0.5mm	Primary
Clay Mineral	10%	<0.01-0.3mm	Primary / Secondary
Feldspar	5.0%	0.2-0.4mm	Primary
Muscovite	<0.5%	0.1-0.6mm	Primary
Ilmenite	<0.5%	<0.1mm	Primary
Hæmatite	<0.5%	<0.2mm	Primary / also weathered

DIAGNOSIS:

GREY SANDSTONE

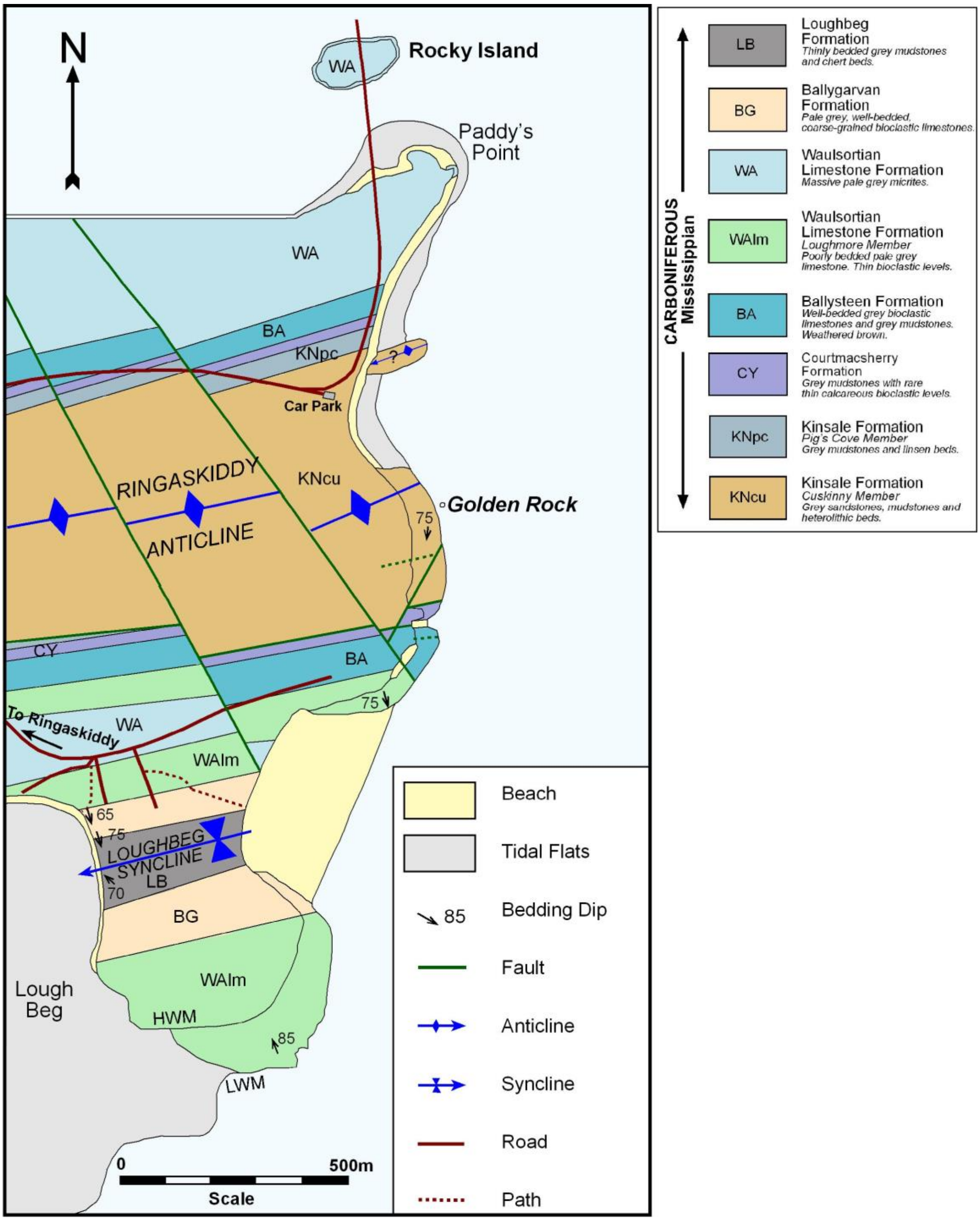
	**BH 09-EC, 43.00m** Hand specimen cm scale Light grey, medium-grained, sandstone with quartz veins, slightly vuggy texture
	Plane Polarised Light. Field of view: 3mm Medium-grained, well-sorted sandstone texture
	Crossed polarised light. Solutional contacts between quartz grains are visible e.g. top centre Rounded clay mineral grains are also visible (bottom centre)

Appendix A9-General joint characteristics in bedrock outcrops at Cork Dockyard area

Descriptors/Values shown in red correspond to the range of joint characteristics present without attempting to quantify the proportion of joints in each category. The extremely limited outcrop width does not permit the identification of joint persistence beyond P2 or P3 values. Hence, some of the joints within the P2 range described here could in fact have a much greater persistence.

	A	B	C	D
1	SPACING	MOISTURE	OPENNESS	PERSISTENCE
2	J1- <20mm	M1 Dry	O1-0mm	P1-<1m
3	J2- 20-60mm	M2 Dry but capable of flow	O2-<1mm	P2-1-3m
4	J3- 60-200mm	M3 Dry but staining, leaching, vegatation	O3-1-3mm	P3-3-10m
5	J4- 200-400mm	M4 Filling damp, evidence of flow	O4-3-10mm	P4-10-20m
6	J5-400-600mm	M5 Seepage	O5-10-30mm	P5->20m
7	J6->600-800mm	M6 Continuous flow	O6->30mm	
8	J7- 800-1000mm	M7 Continuous flow under high pressure		*Minimum values*
9	J8-1000-2000mm			*for these joints*
10	J9->2000mm			
11				
12	BLOCK SIZES (J/m3)	BLOCK SIZES (mm)	BLOCK TYPE	
13	SJ1-<1	S1-<60mm	T1 Polyhedral	
14	SJ2-1-3	S2-60-200mm	T2 Tabular	
15	SJ3-3-10	S3-200-300mm	T3 Prismmatic	
16	SJ4-10-30	S4-300-600mm	T4 Equidimensional	
17	SJ5-30-60	S5-600-1000m	T5 Rhomboherdal	
18	SJ6>60	S6-1000-2000mm	T6 Columnar	
19				
20	*mostly SJ1-SJ3*			
21				
22	PATTERN	PLANE FORM	FILLING	
23	A-Orthogonal +	PF1 Stepped Rough	F1 Clean	
24	B-Non orthogonal X	PF2 Stepped Smooth	F2 Surface staining	
25	C-Orthogonal T	PF3 Stepped Slickensided	F3 Non cohesive	
26	D-Non orthogonal one persistent set	PF4 Undulating Rough	F4 Inactive clay	
27	E-Orthogonal both sets discontinuous	PF5 Undulating Smooth	F5 Swelling clay	
28	F-Non orthogonal both sets discontinuous	PF6 Undulating Slickensided	F6 Cemented	
29	G-Triple intersections with all joints	PF7 Planar Rough	F7 Minerals	
30	H-Triple intersections with 120deg angles	PF8 Planar Smooth		
31		PF9 Planar Slickensided	Cannot rule out F5	

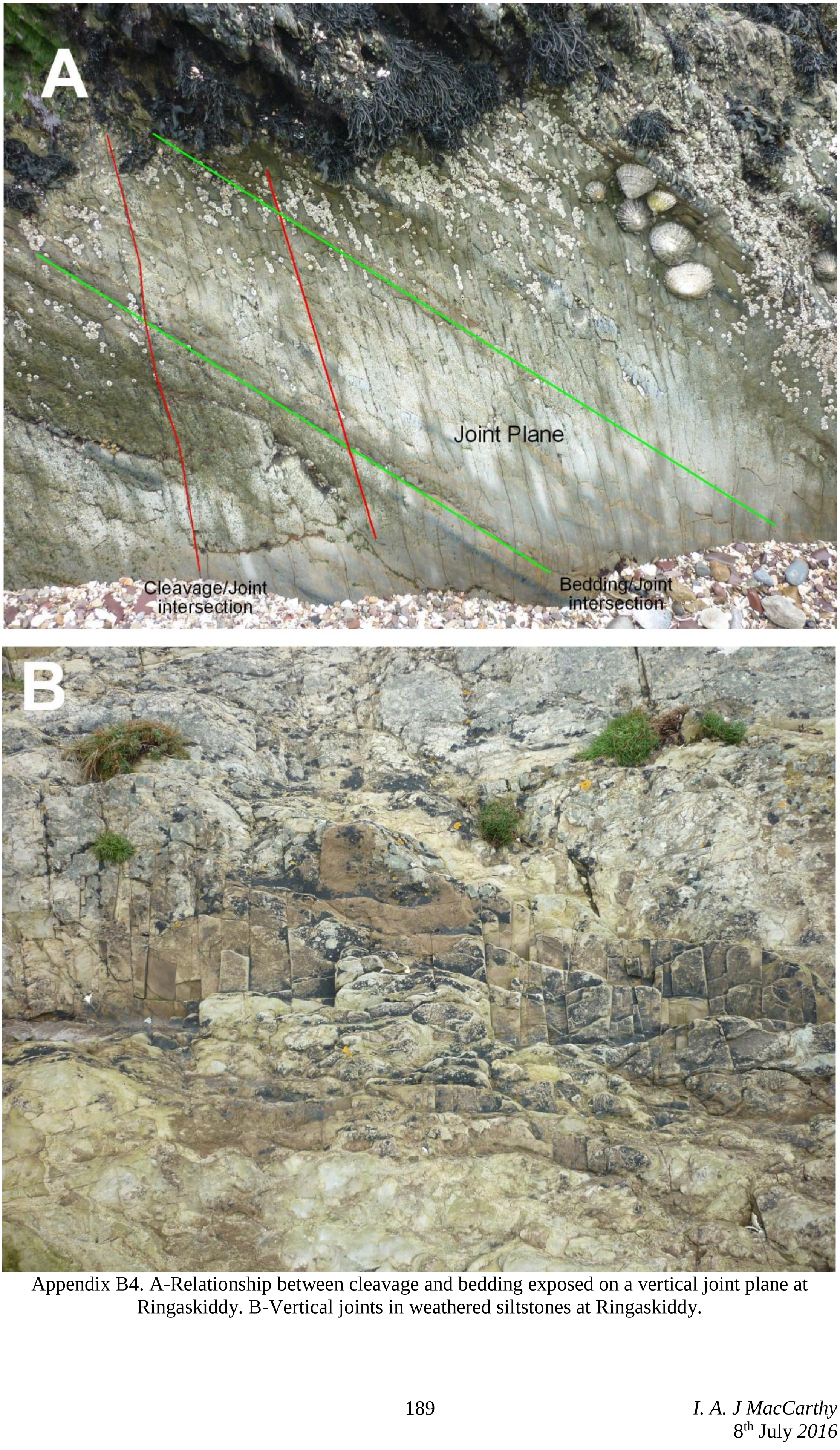
APPENDIX B-Representative examples of the bedrock in the Cork Harbour area



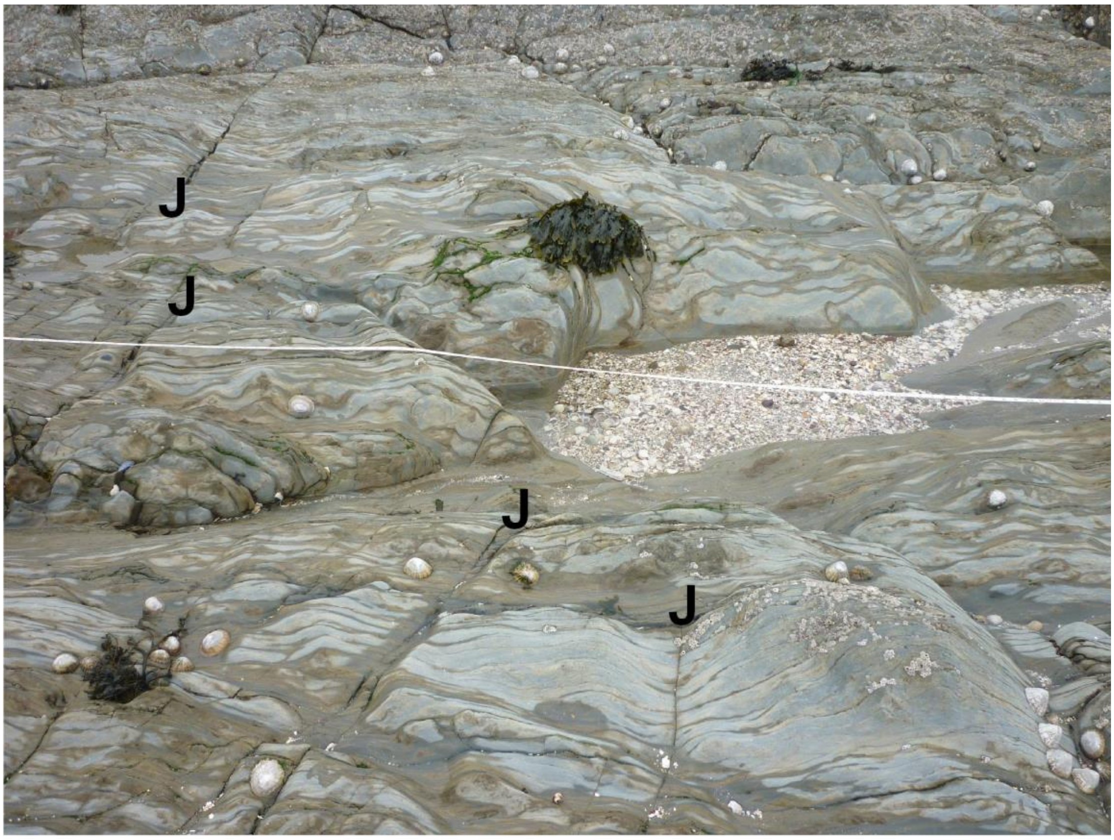
Appendix B1. Bedrock map of Ringaskiddy coastal section.

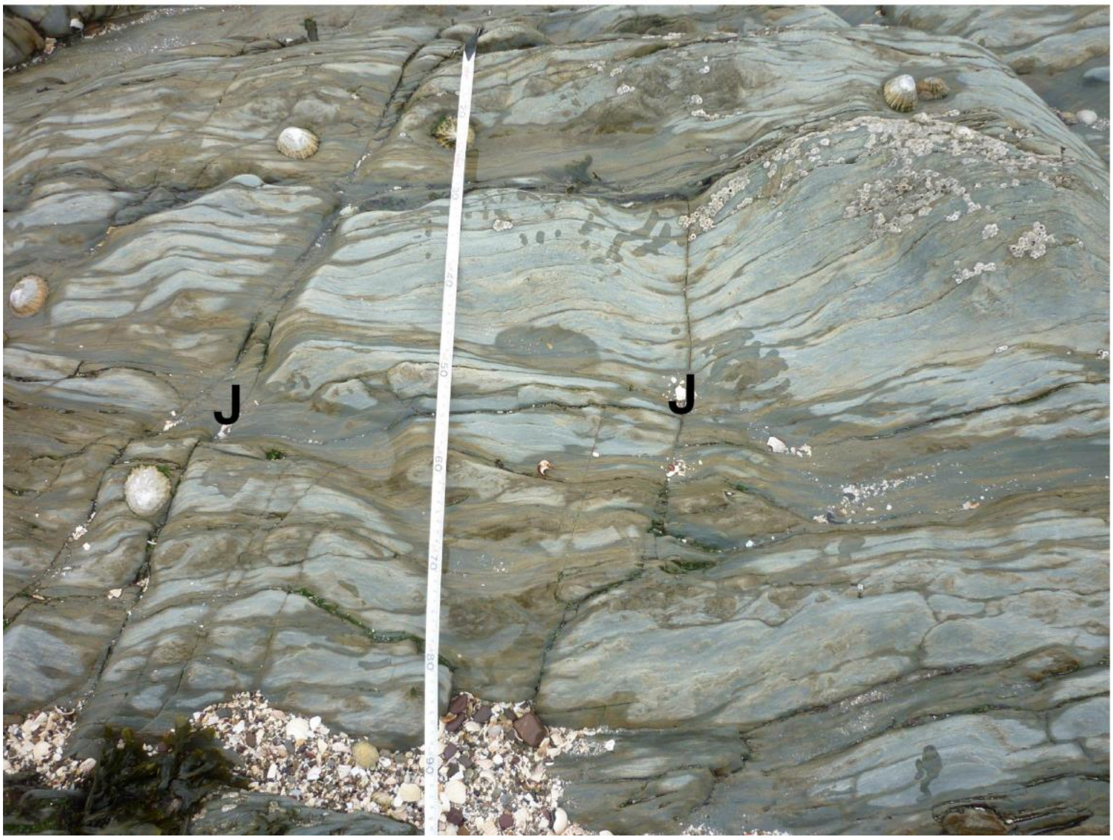
Appendix B2. Aerial view of the Ringaskiddy coastal section showing the bedrock.

Appendix B3. Jointing pattern (arrows) in the Kinsale Formation Cuskinny Member at Ringaskiddy. The bedrock is almost entirely composed of heterolithic beds. Many of the joints have infills of white vein quartz (arrows). View northwards. Bedding planes dip towards the viewer.



Appendix B4. A-Relationship between cleavage and bedding exposed on a vertical joint plane at Ringaskiddy. B-Vertical joints in weathered siltstones at Ringaskiddy.



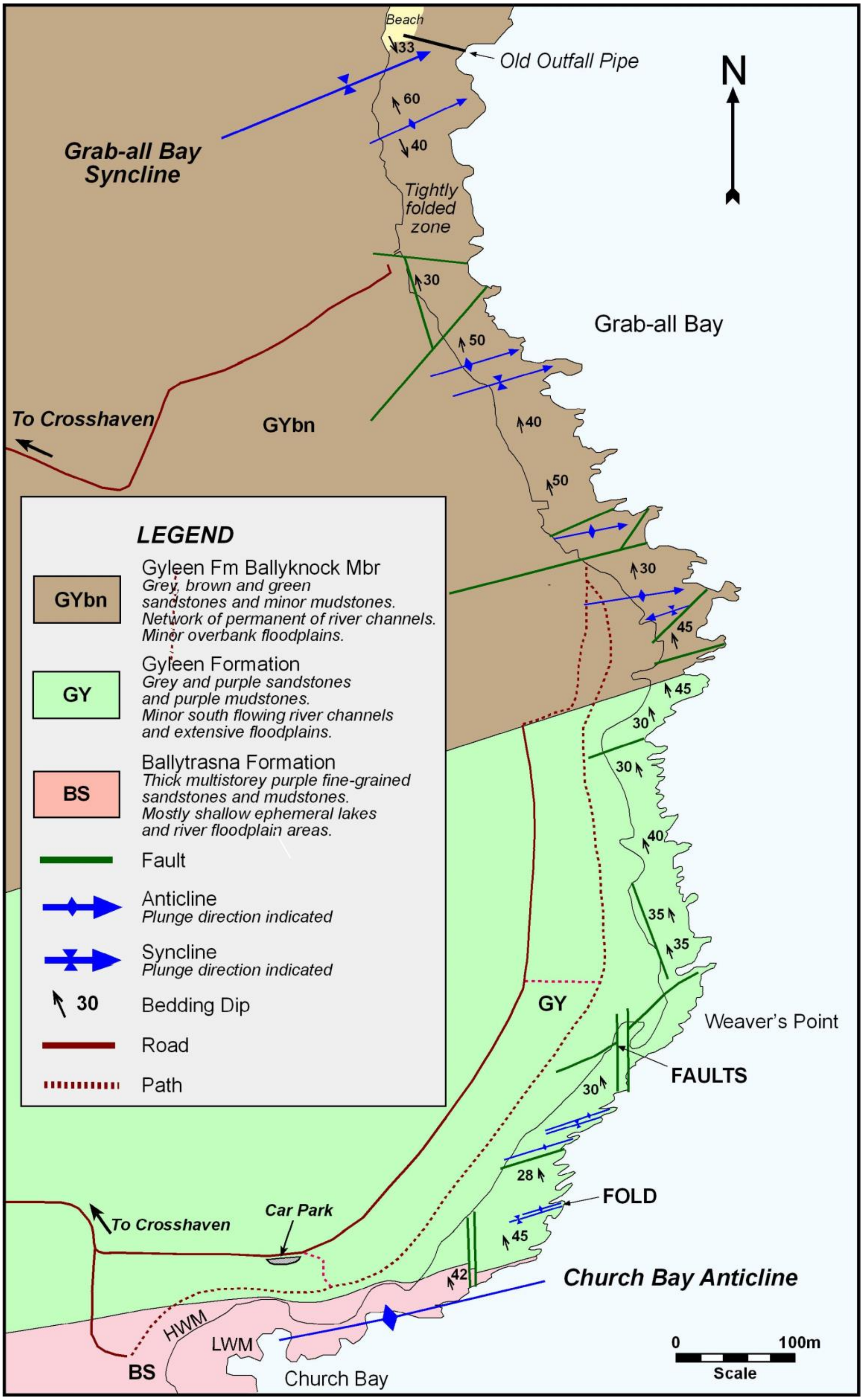


Appendix B5. Examples of jointing (J) in the Cuskinny Member at Ringaskiddy.

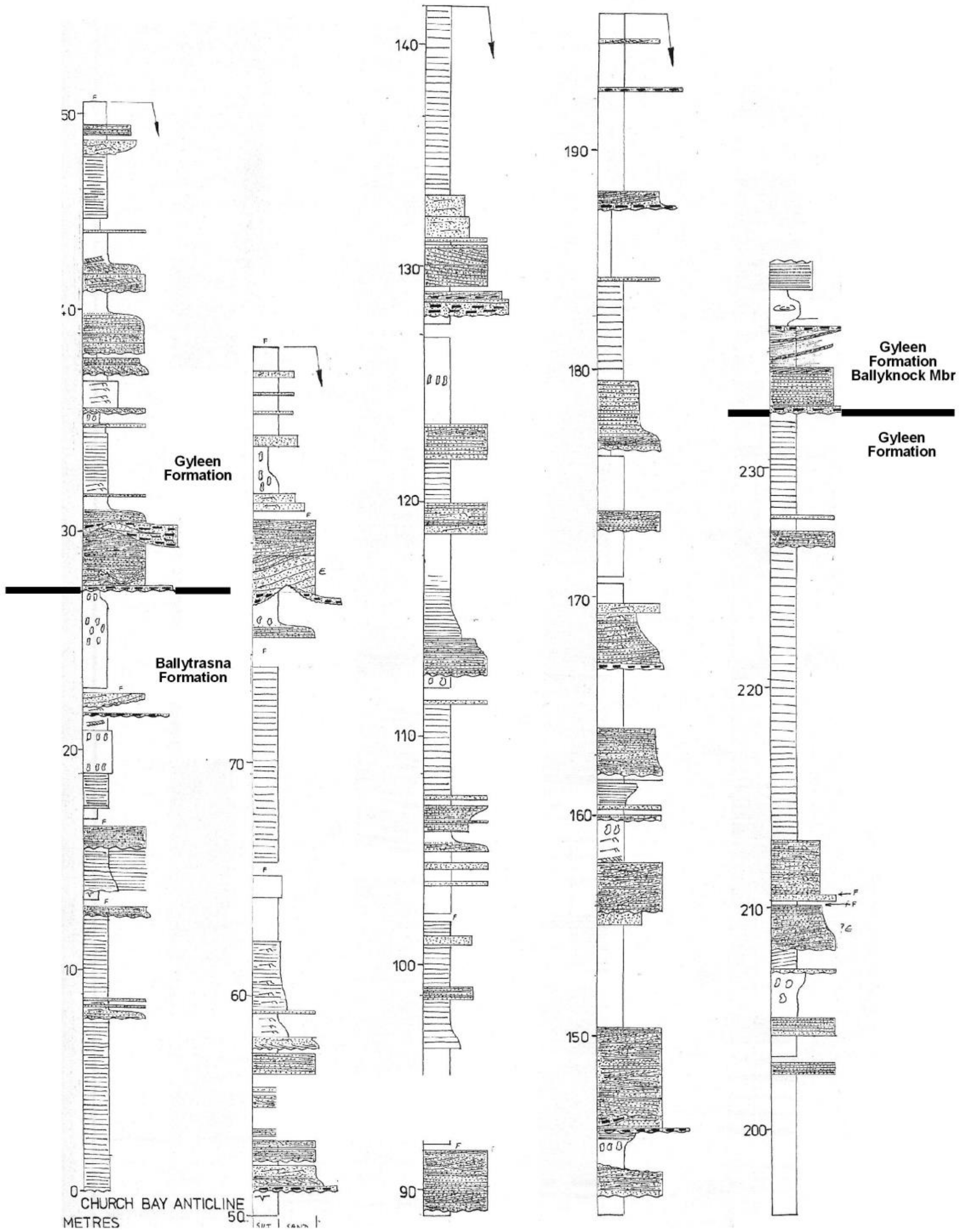
Appendix B6. Ballysteen Formation at Ringaskiddy.

Appendix B7. Jointing in the Ballysteen Formation at Ringaskiddy.

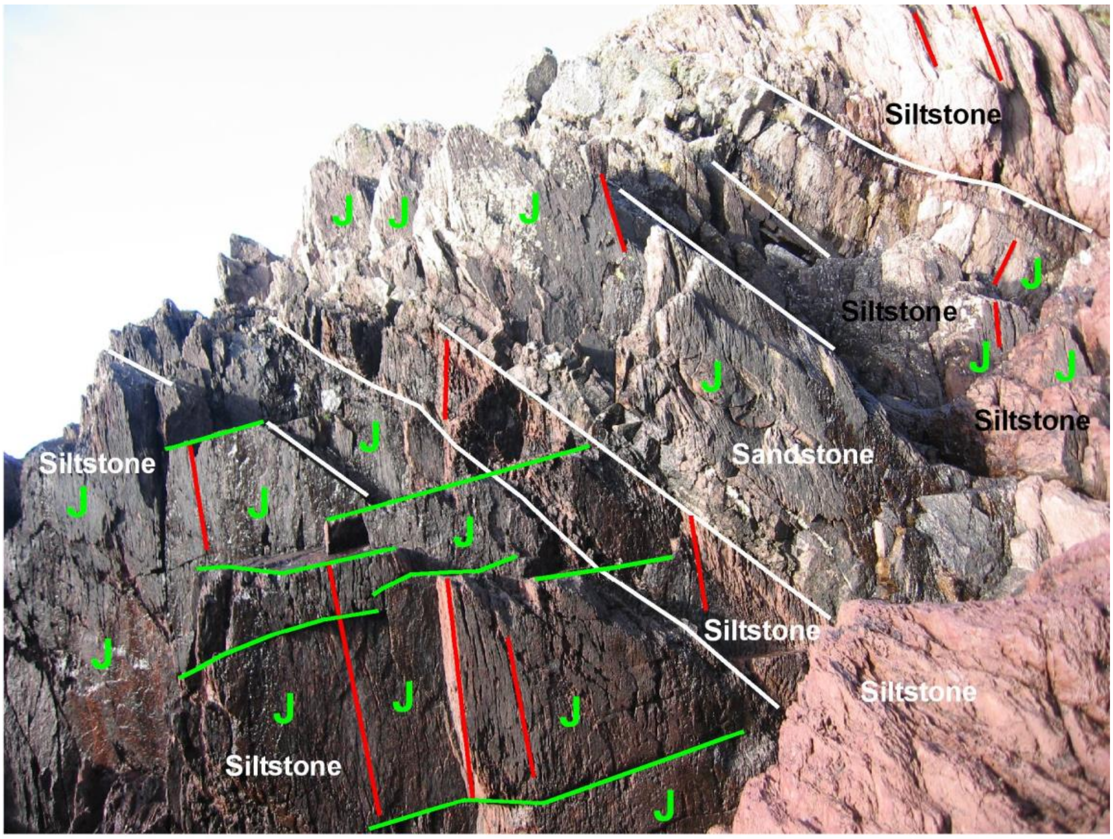

Appendix B8. Calcite veining in the Waulsortian Limestones at Ringaskiddy.



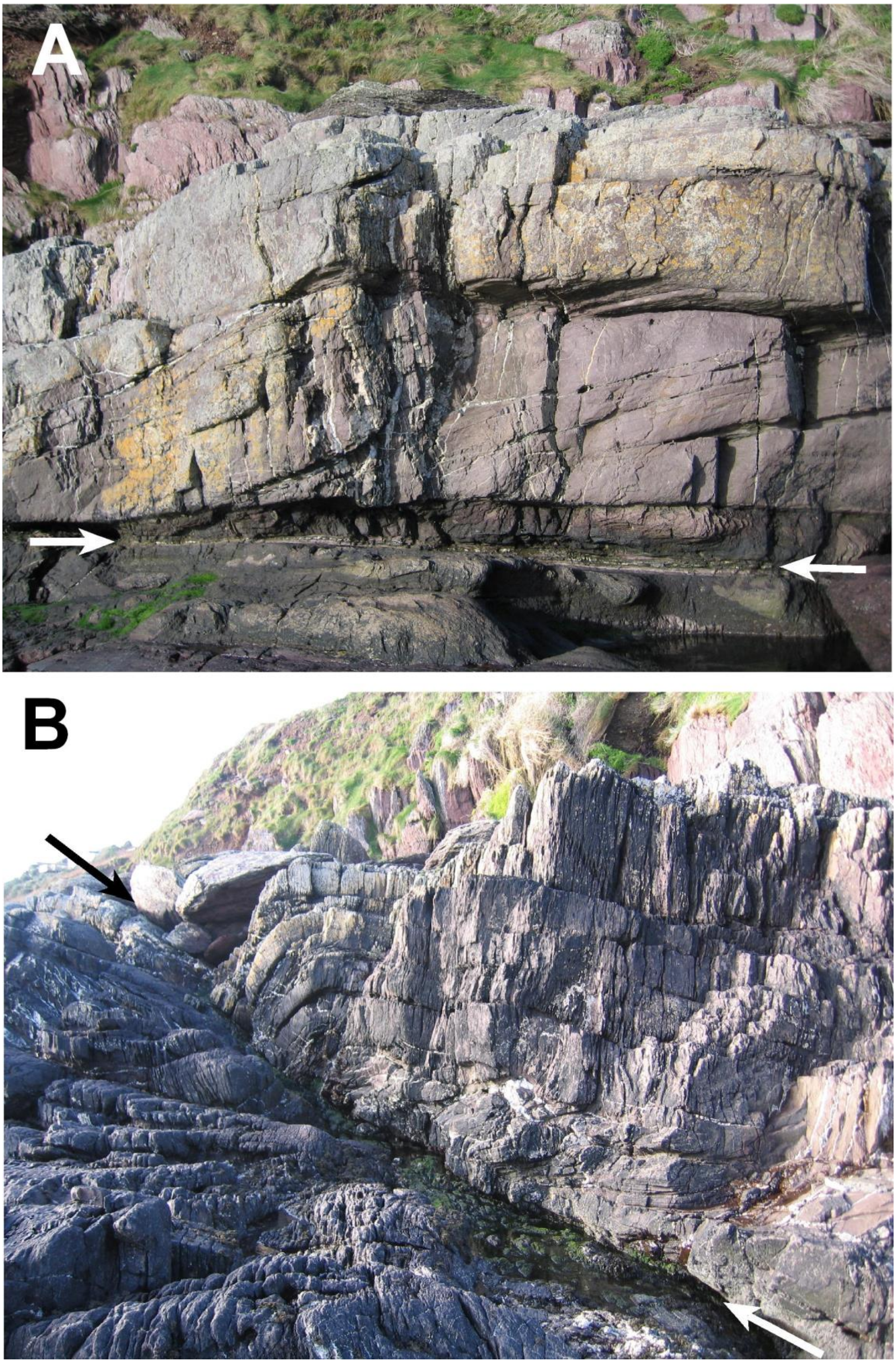
Appendix B9. Bedrock map of Church Bay-Graball Bay.



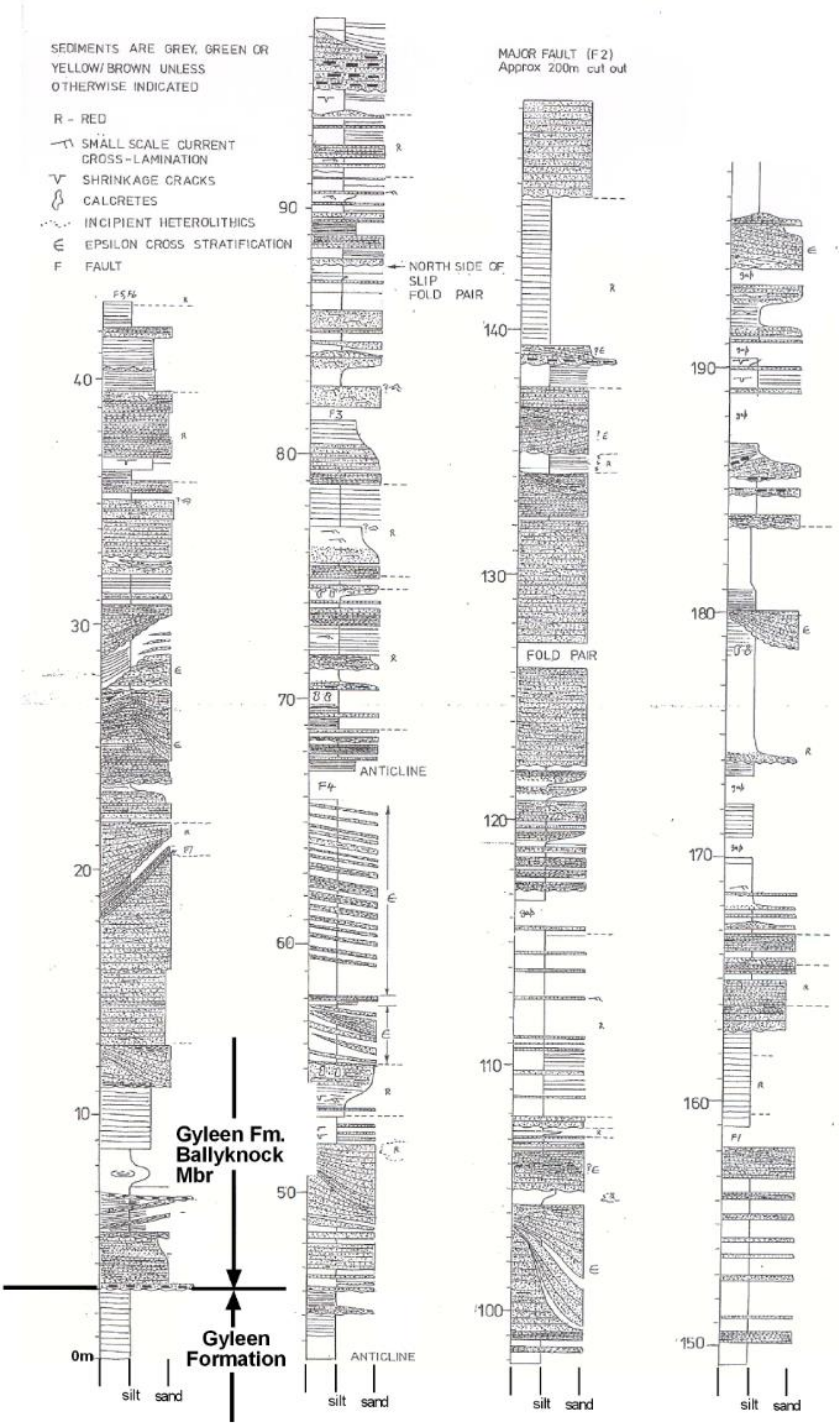
Appendix B10. Representative log of the Gyleen Formation at Church Bay.



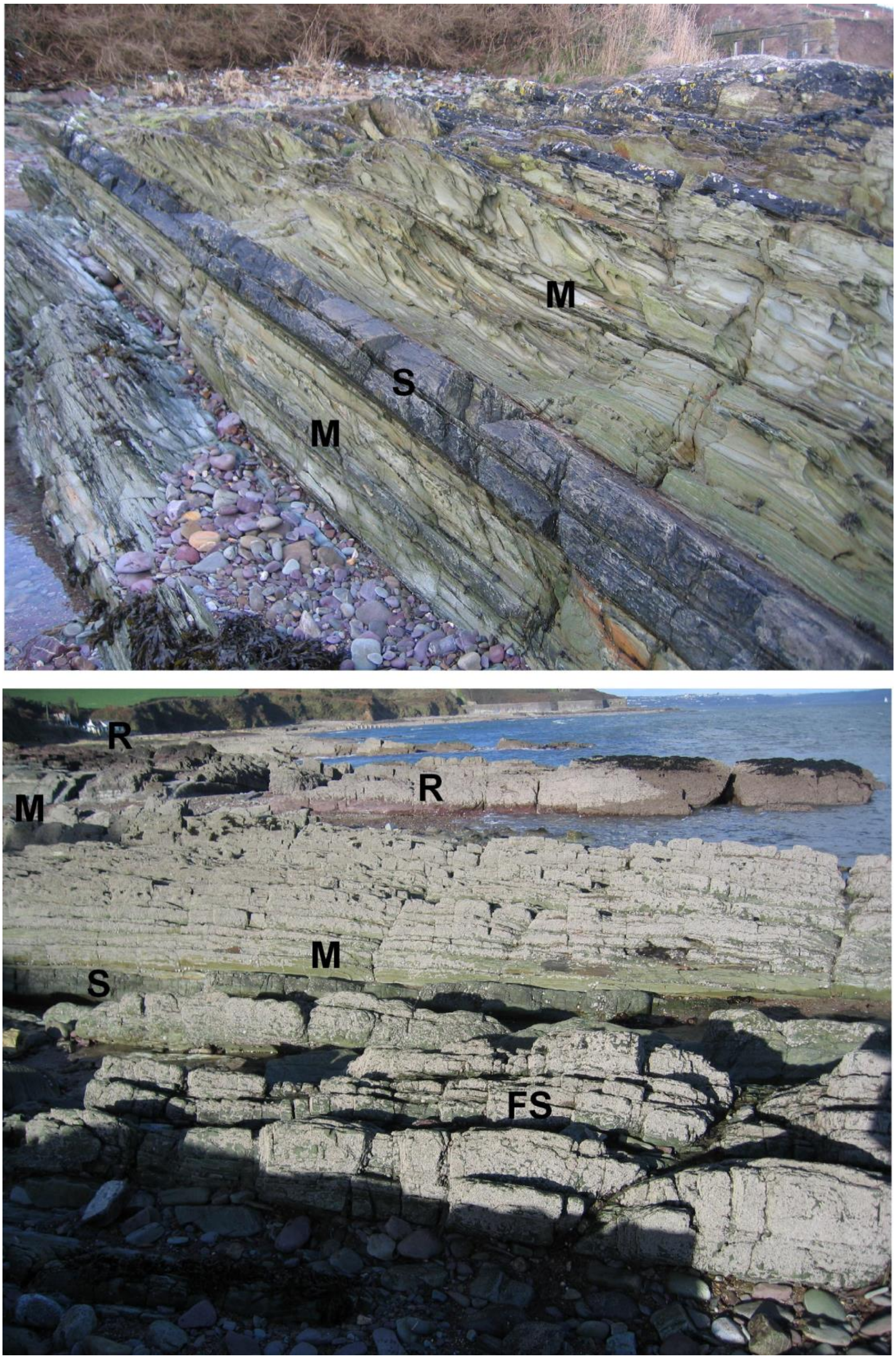
Appendix B11. Examples of structures in the Ballytrasna-Gyleen Formations.
J-Joints, White lines-Bedding, Red lines-Cleavage.



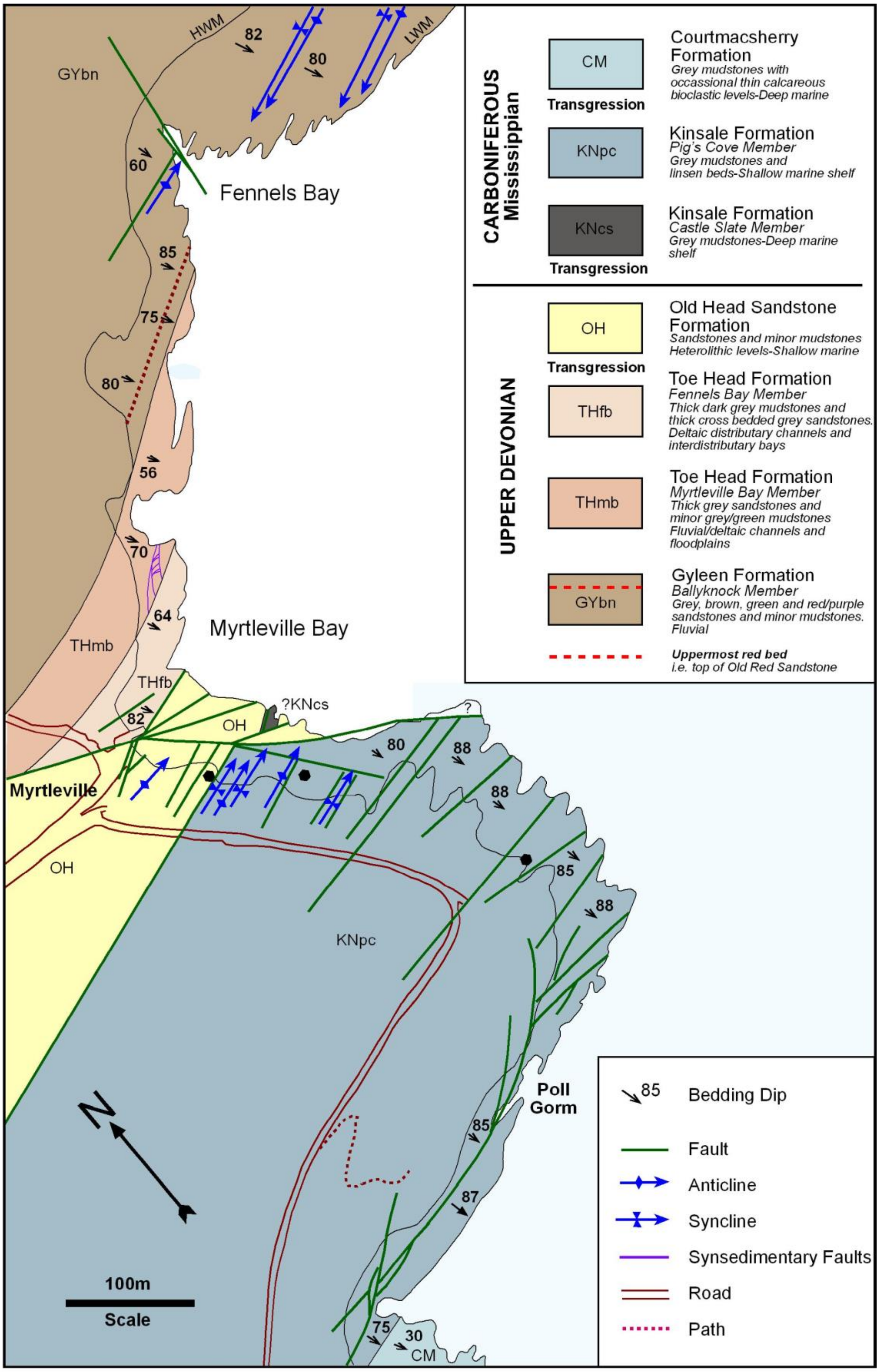
Appendix B12. Examples of faulting (between arrows) at Weavers Point.



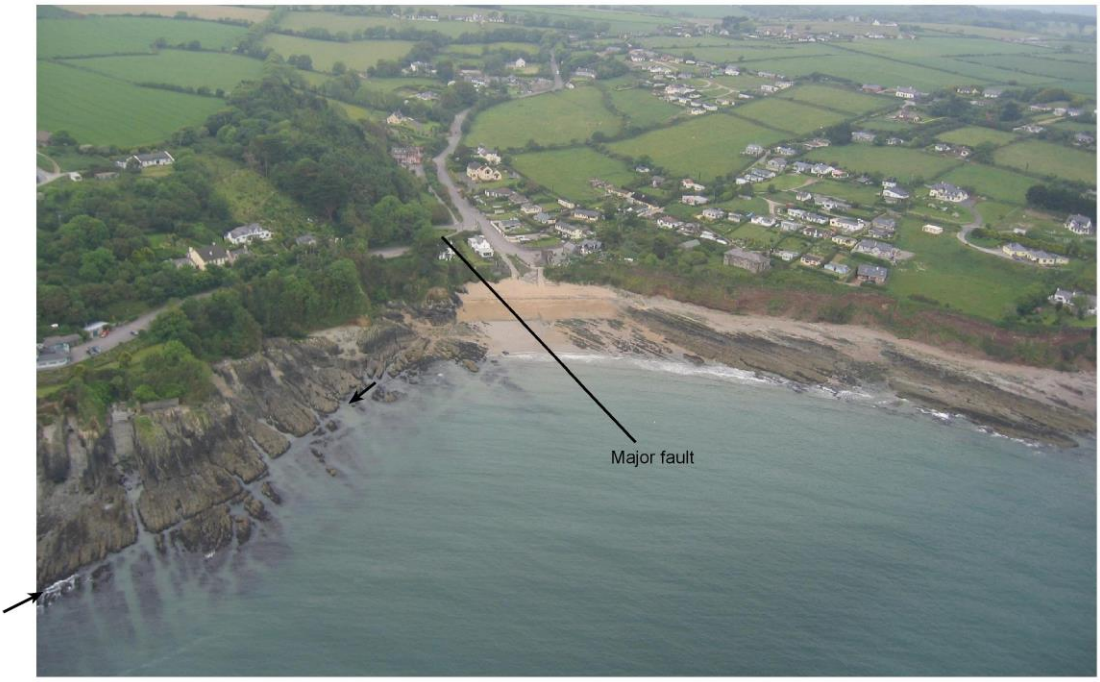
Appendix B13. Representative log of the Gyleen Formation Ballyknock Mbr.



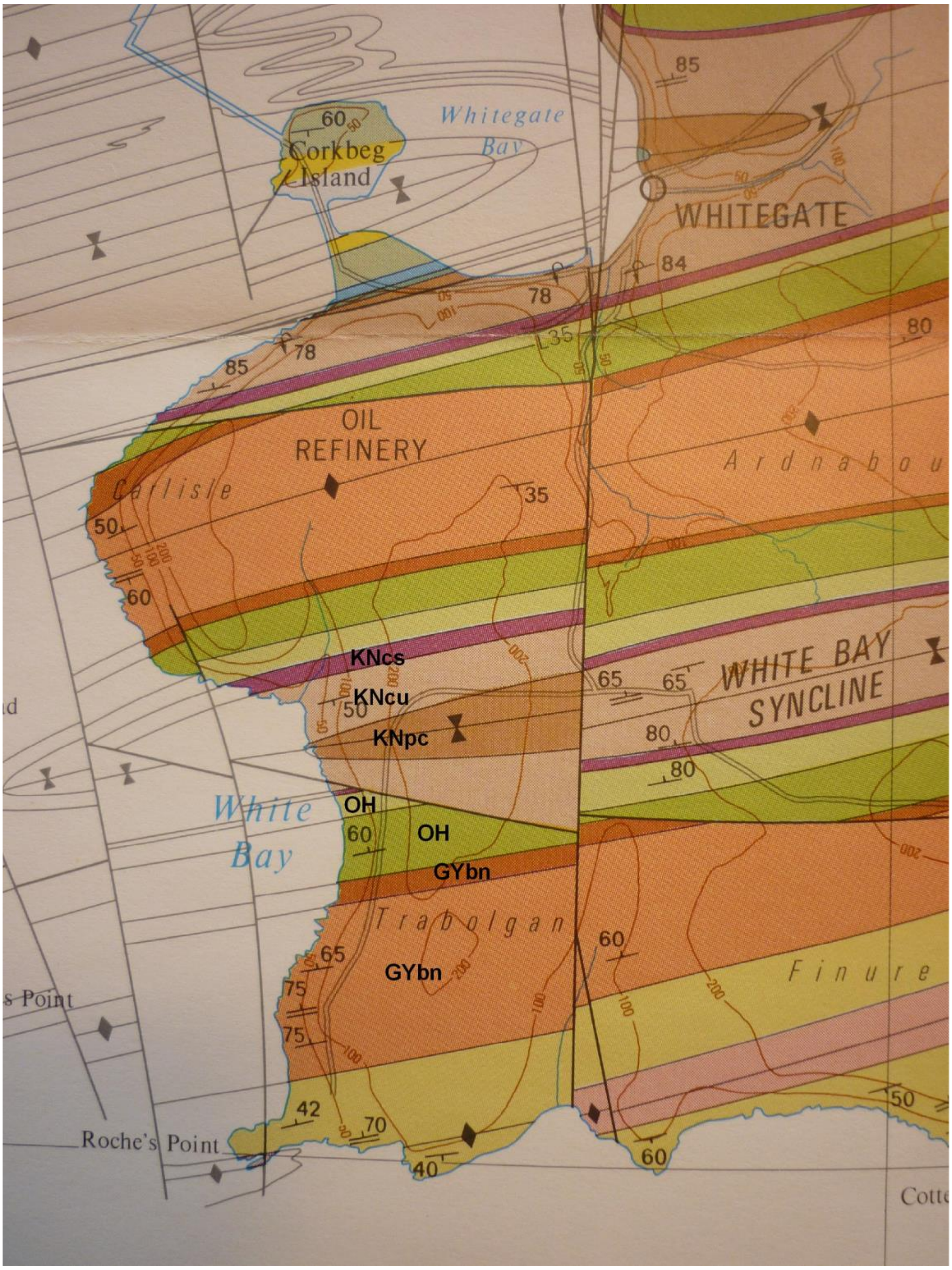
Appendix B14. Representative photo of the Gyleen Formation Ballyknock Mbr.



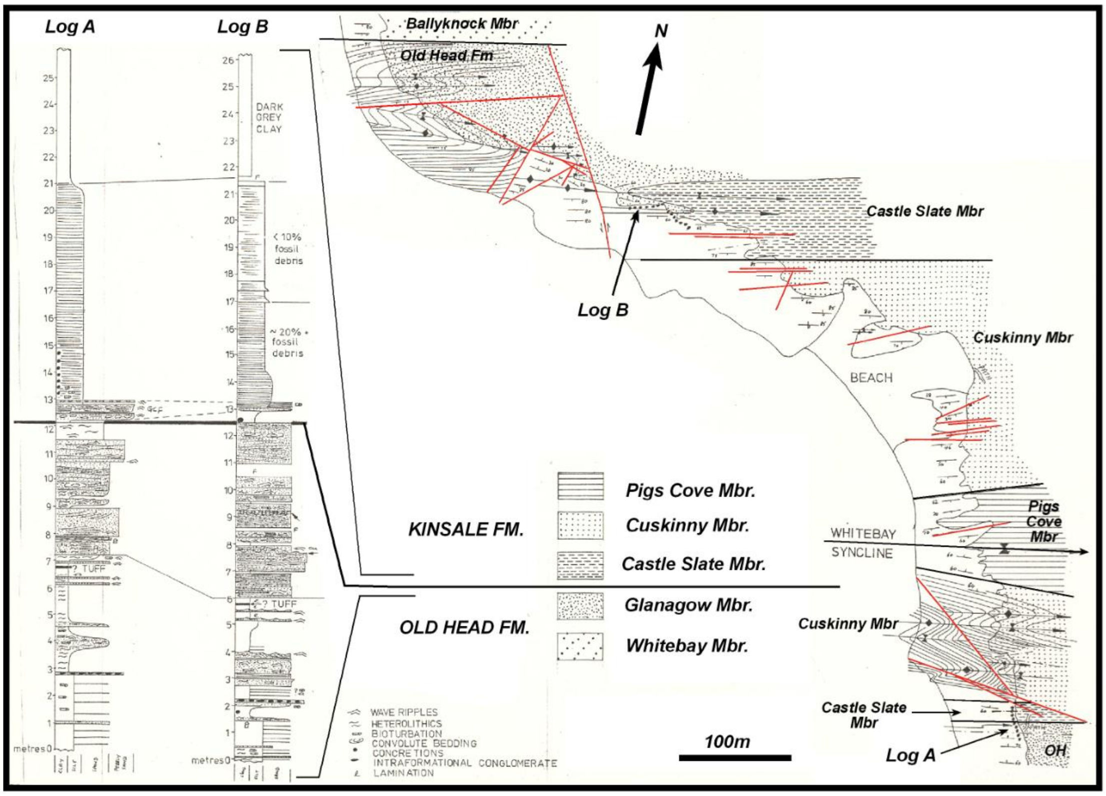
Appendix B15. Geological map of the bedrock at Myrtleville.



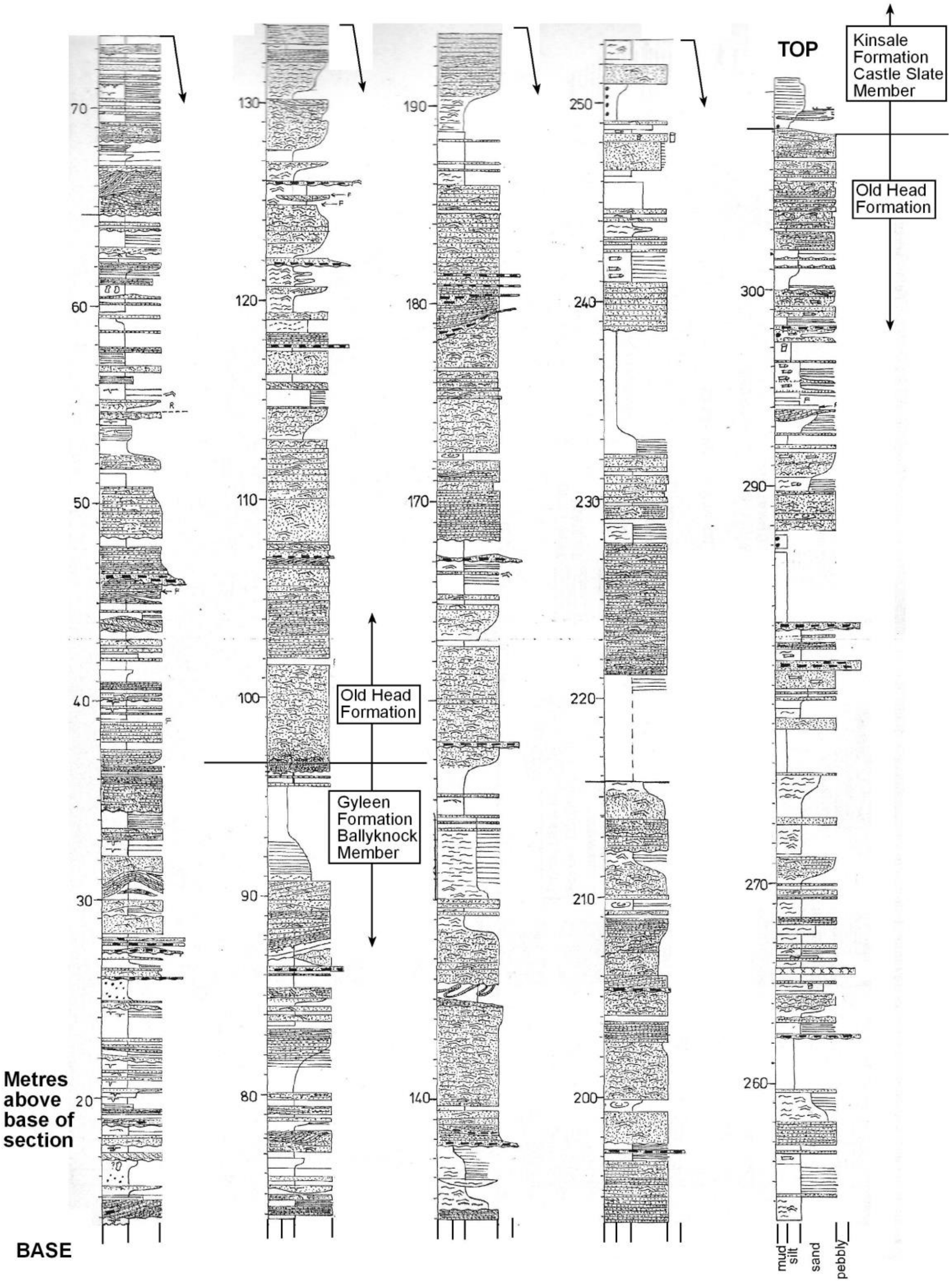
Appendix B16. Faulting at Myrtleville indicated by arrows.



Appendix B17. Bedrock map of Whitebay area.

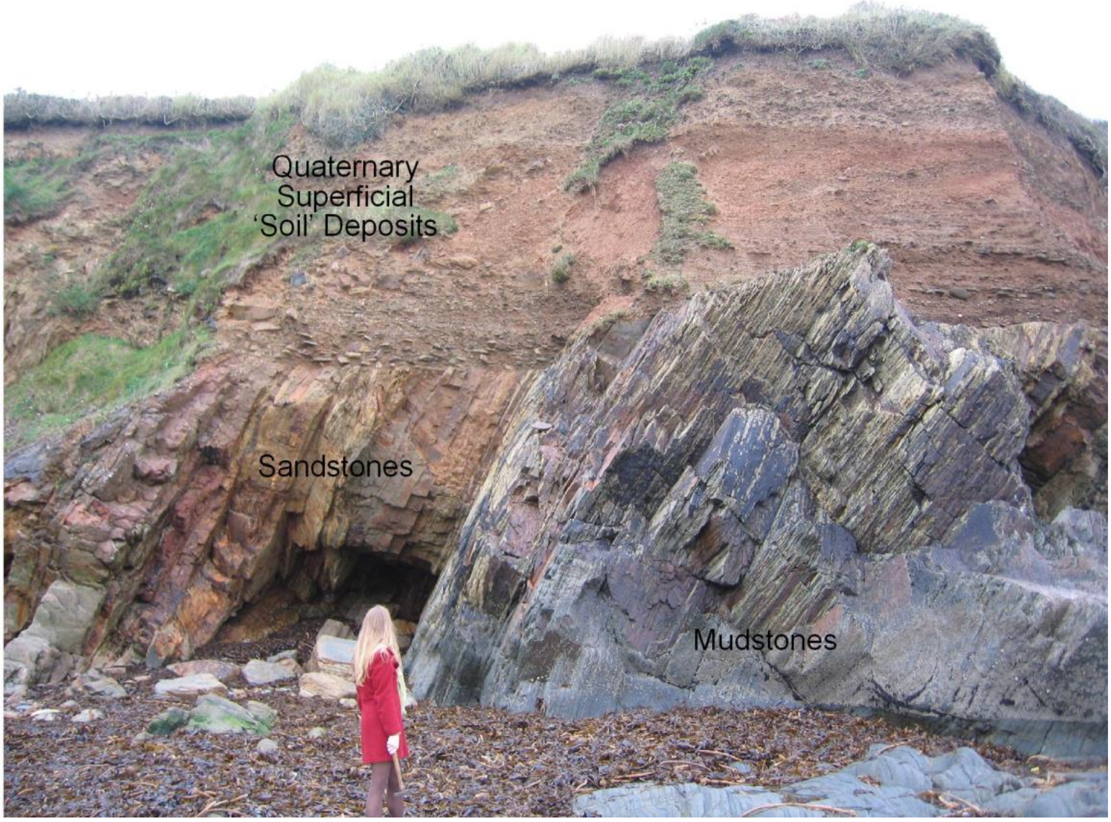


Appendix B18. Detailed bedrock map of Whitebay area.



Appendix B19. Lithological log of the Gyleen Formation Ballyknock Member and the Old Head Formation at Whitebay.

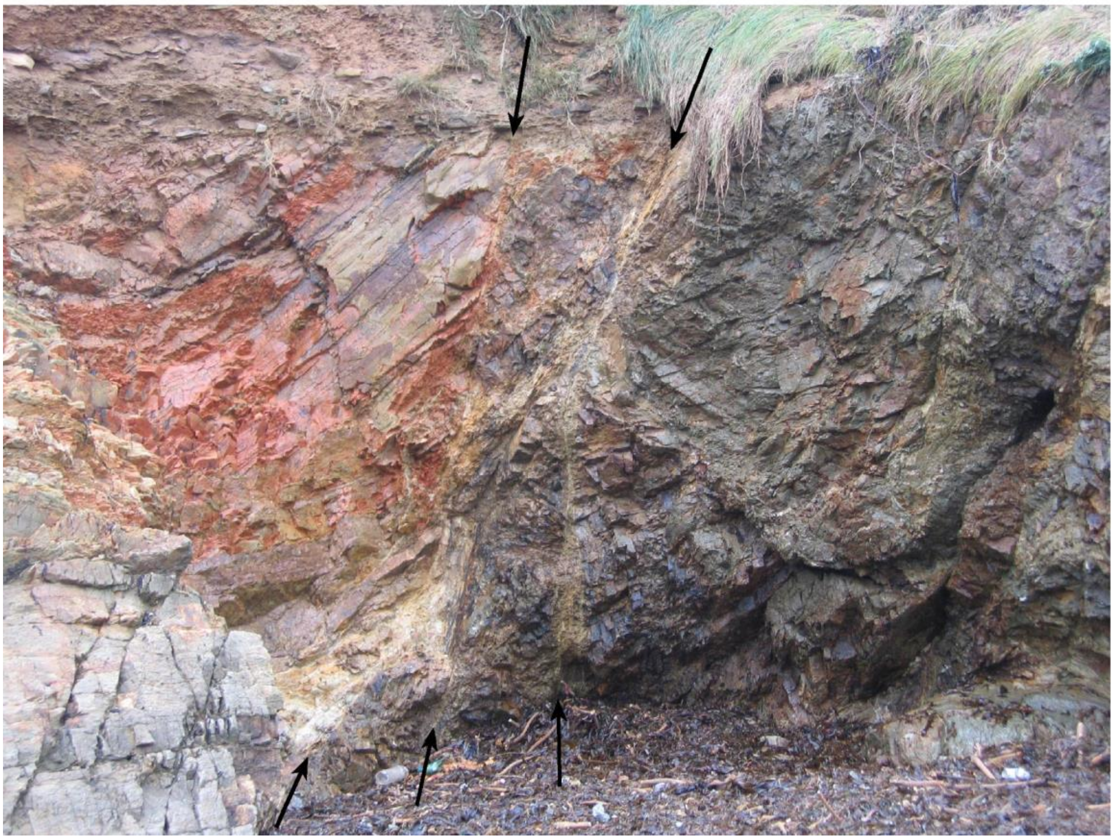
Appendix B20. Sandstones and heterolithic sediments of the Old Head Formation at Whitebay. The pale coloured level is a volcanic tuff.



Appendix B21. Examples of the Kinsale Formation Cuskinny and Pig's Cove Members at Whitebay.
J-Joint planes.

Appendix B22. The Kinsale Formation Castle Slate Member.

Appendix B23. The Kinsale Formation Castle Slate Member showing jointing, fracturing and lamination.



Appendix B24. Faulting at Whitebay indicated by white dash line in upper photo and arrows in lower photo. The red discolouration may be due to post-deformation circulation of hydrothermal fluids. Note associated folding in upper photo and intense fracturing of the bedrock in lower photo.

APPENDIX C-Nomenclature and Classification Schemes

Appendix C1. Classification of sandstones

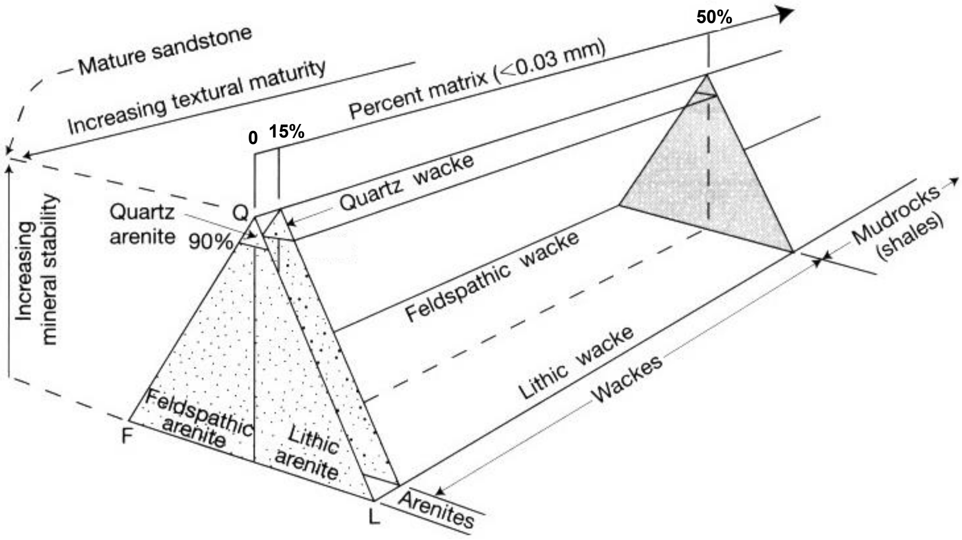
Sandstones can be classified on the basis of their Textural and/or Compositional characteristics.

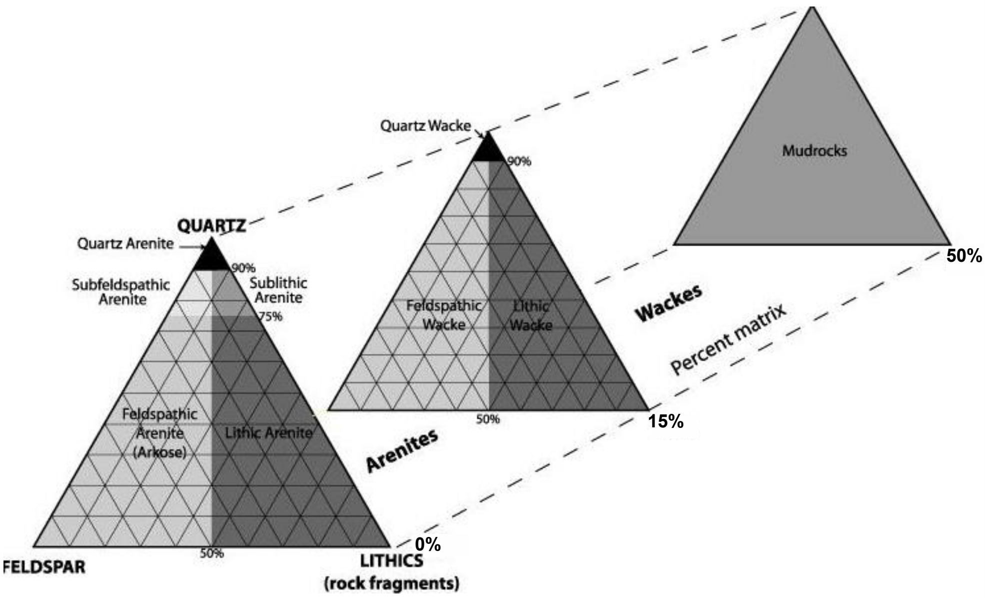
Textural Classification of Sandstones

The following classification, the Udden-Wentworth Scale is used for both unconsolidated and lithified sediment. The scheme is based on grain size.

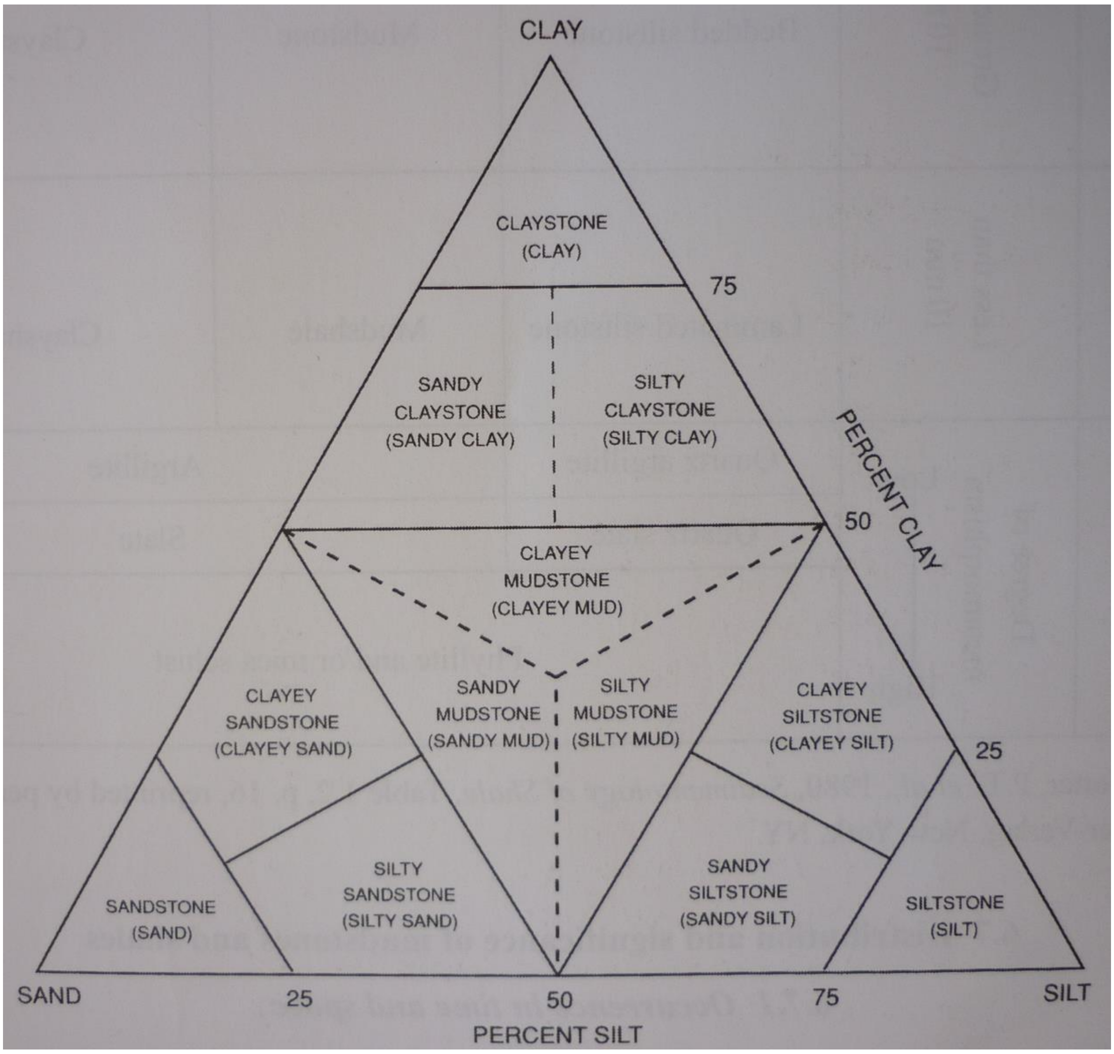
	U.S. Standard sieve mesh	Millimeters		Phi (ϕ) units	Wentworth size class
GRAVEL		4096		−12	
		1024		−10	Boulder
		256	256	− 8	
		64	64	− 6	Cobble
		16		− 4	Pebble
	5	4	4	− 2	
	6	3.36		− 1.75	
	7	2.83		− 1.5	Granule
	8	2.38		− 1.25	
	10	2.00	2	− 1.0	
SAND	12	1.68		− 0.75	
	14	1.41		− 0.5	Very coarse sand
	16	1.19		− 0.25	
	18	1.00	1	0.0	
	20	0.84		0.25	
	25	0.71		0.5	Coarse sand
	30	0.59		0.75	
	35	0.50	½	1.0	
	40	0.42		1.25	
	45	0.35		1.5	Medium sand
	50	0.30		1.75	
	60	0.25	¼	2.0	
	70	0.210		2.25	
	80	0.177		2.5	Fine sand
	100	0.149		2.75	
	120	0.125	⅛	3.0	
	140	0.105		3.25	
	170	0.088		3.5	Very fine sand
	200	0.074		3.75	
	230	0.0625	1/16	4.0	
MUD – SILT	270	0.053		4.25	
	325	0.044		4.5	Coarse silt
		0.037		4.75	
		0.031	1/32	5.0	
		0.0156	1/64	6.0	Medium silt
		0.0078	1/128	7.0	Fine silt
		0.0039	1/256	8.0	Very fine silt
MUD – CLAY		0.0020		9.0	
		0.00098		10.0	Clay
		0.00049		11.0	
		0.00024		12.0	
		0.00012		13.0	
		0.00006		14.0	

Compositional Classification of sandstones
There are many classification schemes for sandstones. Dott's (1964) original scheme modified by Gilbert (1982) is based on (1) the mineralogy of framework grains and (2) on the proportion of matrix present between the framework grains.
The scheme recognizes three types of framework grains: Quartz (Q), Feldspar (F) and Lithic grains (L).
Depending on the proportion of clay matrix, it recognizes two broad sandstone types, Arenites and Wackes. Each of these is further divided
Arenites are sandstone that have less than 15% clay matrix between the framework grains.
Quartz Arenites are sandstones that contain more than 90% siliceous grains.
Feldspathic Arenites are sandstones that contain less than 90% quartz and more feldspar than unstable lithic fragments and minor minerals. Sub-feldspathic arenites contain 75-90% quartz.
Lithic Arenites have a high content of unstable lithic fragments. These contain less than 90% quartz grains and more unstable rock fragments than feldspars. Sub-lithic arenites contain 75-90% quartz.
Wackes are sandstones that contain more than 15% clay matrix in between the framework grains.
Quartz Wackes are quartz arenites that contain more that 15% matrix.
Felspathic Wackes are feldspathic sandstones that contain more than 15% matrix.
Lithic Wackes are sandstones in which the matrix greater than 15%.


Mature sandstone
Increasing textural maturity
Percent matrix (<0.03 mm)
50%
0 15%
Quartz wacke
Increasing mineral stability
Quartz arenite
Q
90%
Feldspathic wacke
Mudrocks (shales)
Lithic wacke
Wackes
Feldspathic arenite
Lithic arenite
F
L
Arenites


Mudrocks
50%
Quartz Wacke
90%
Feldspathic Wacke
Lithic Wacke
Wackes
50%
15%
Percent matrix
QUARTZ
Quartz Arenite
90%
Subfeldspathic Arenite
Sublithic Arenite
75%
Feldspathic Arenite (Arkose)
Lithic Arenite
Arenites
0%
FELDSPAR
50%
LITHICS (rock fragments)

Appendix C2. Textural classification of fine-grained rocks and sediments.



Mudstone (Shales)

These are composed of particles of silt and clay that are less than 0.06mm in size. They are commonly referred to as *Shales* when they bear a distinct lamination or fissile character. The classification of mudstones is complex with several systems used based on mineral composition and texture. The constituent particles or clasts in mudstones are not visible with a hand lens or petrographical microscope and can only be examined by x-ray analysis or other techniques.

The classification scheme used in this report recognises the general term *Mudstone* as the class name for all rock of grain size less than 0.06mm. This class is divided into *claystones* (<0.003mm) and *siltstones* (0.003-0.06mm).

Siltstones can be subdivided into *Siltstones, Clayey Siltstone* and *Sandy Siltstone.*

Claystones can be divided into *Claystones, Silty Claystones* and *Sandy Claystones.*

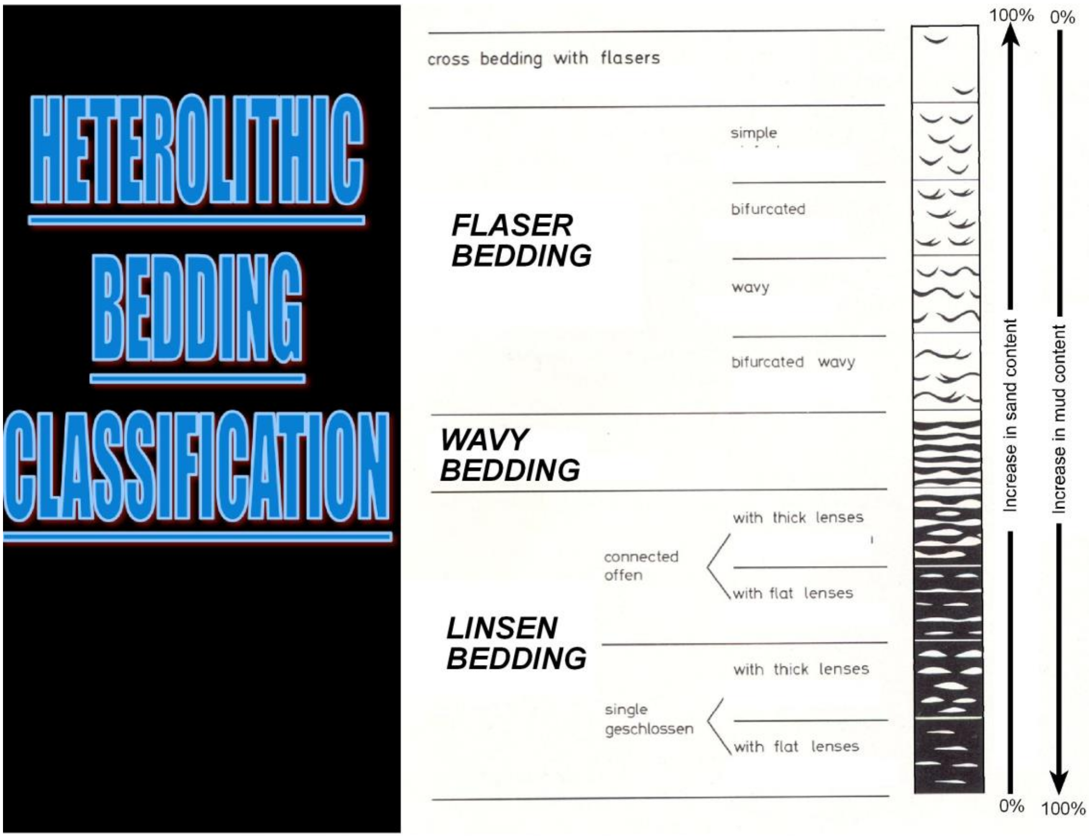
Prefixes (such as laminated, bedded, massive etc.) can be used as required to further qualify descriptions.

The identification of the types of mudstones in this report is based on visual inspection with the aid of a hand lens.

I. A. J MacCarthy
8th July *2016*

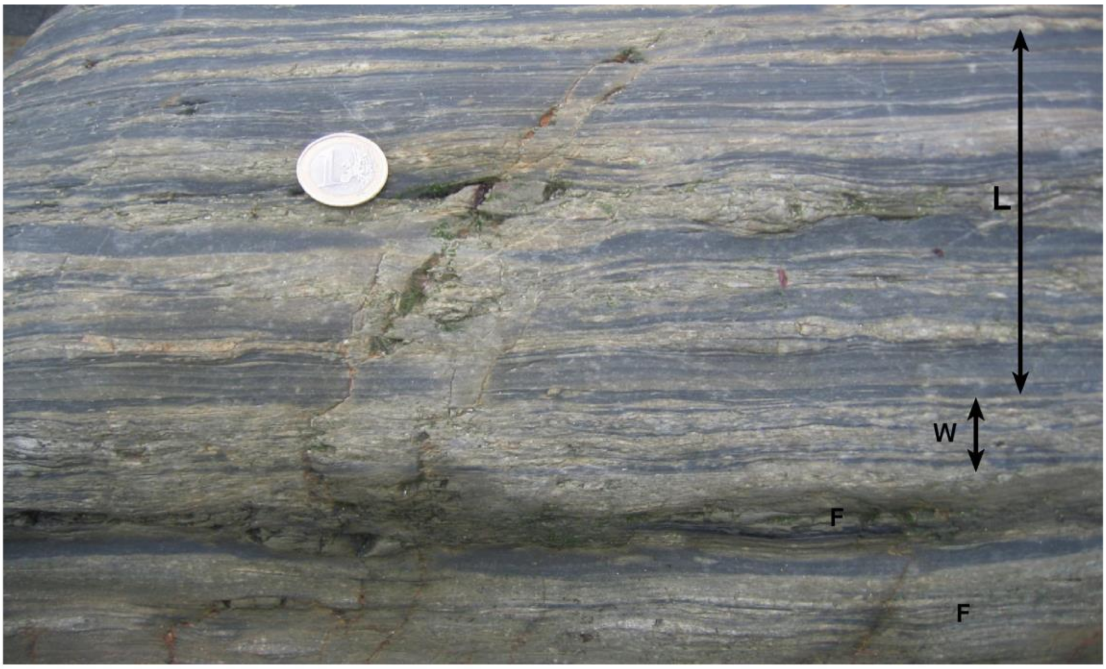
Appendix C3. Classification of Heterolithic bedding

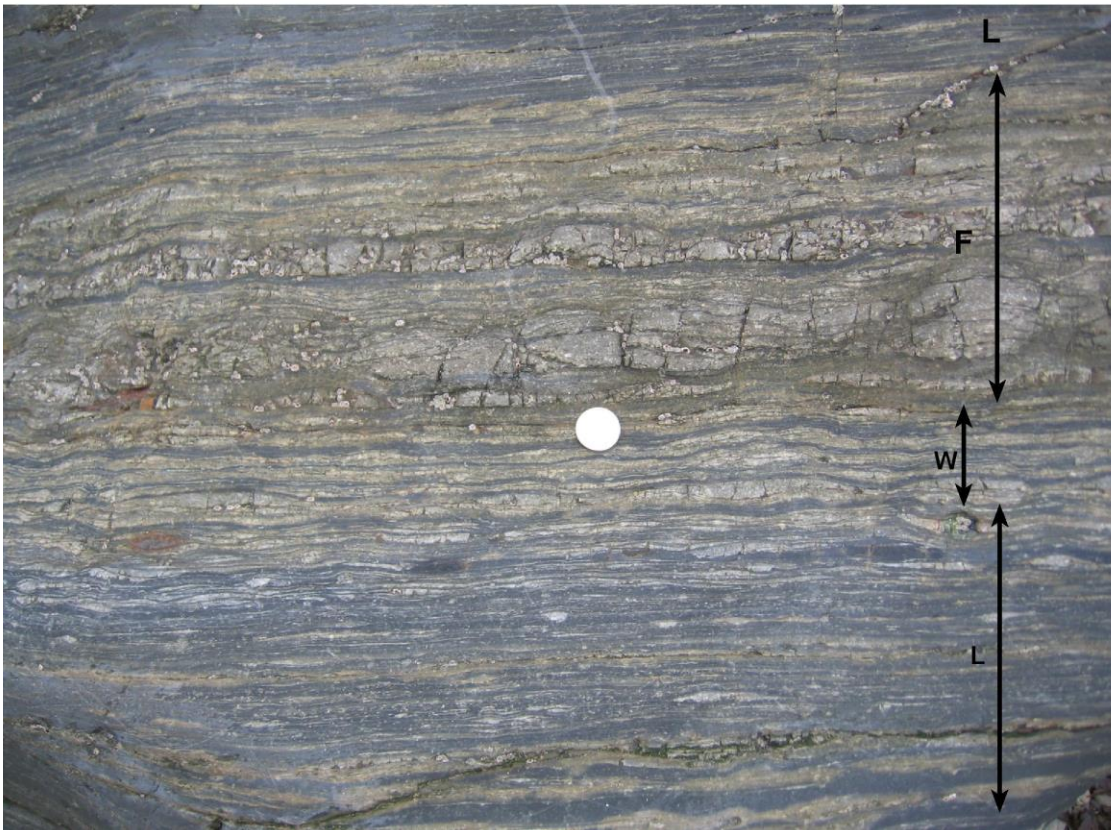
Heterolithic Beds are sedimentary rocks in which there is a rapid alternation of thin (<10mm) layers of sandstone alternating intricately with mudstones.



Schematic classification of heterolithic bedding in sedimentary rocks.

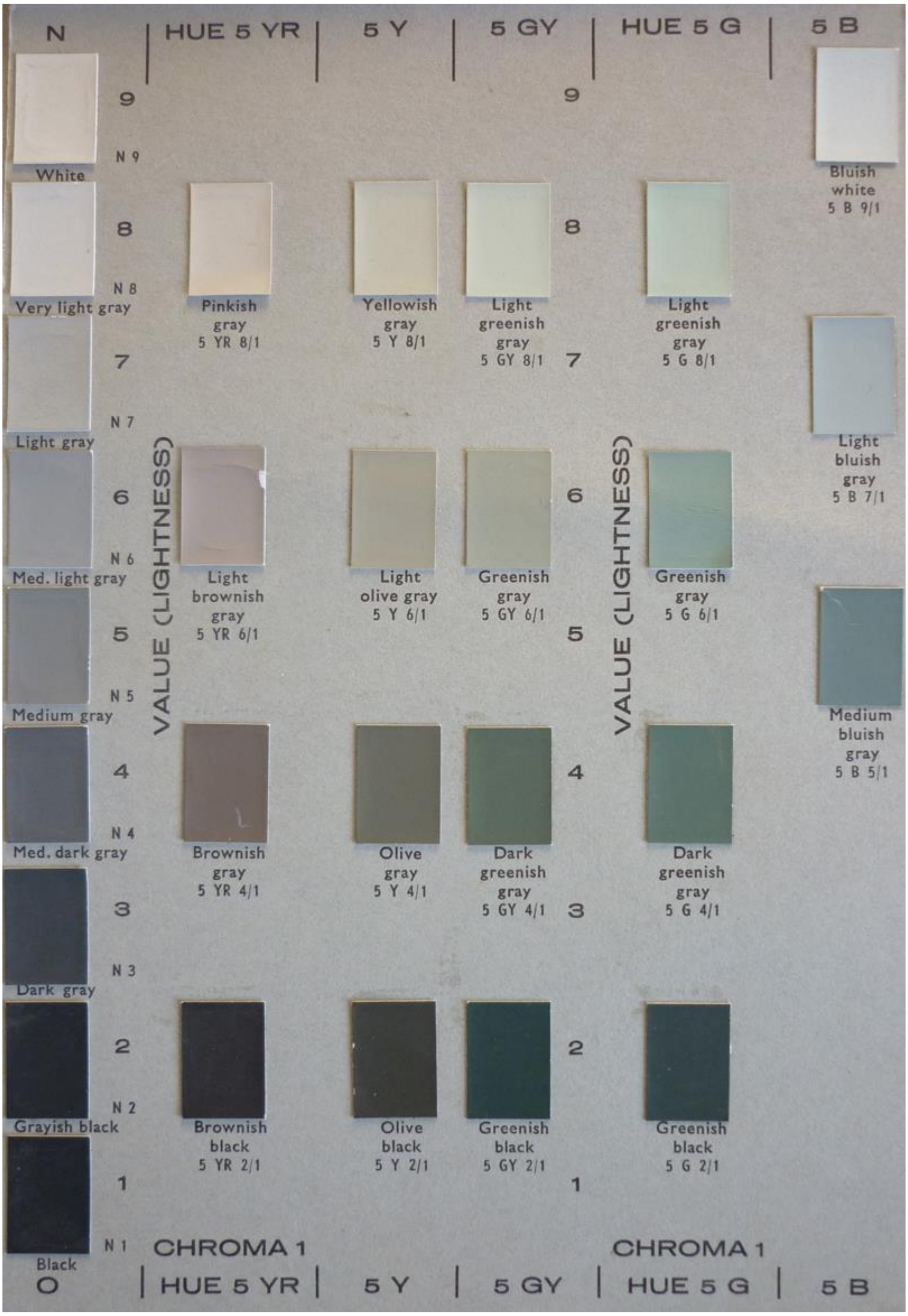
Heterolithic linsen bedding in sedimentary rocks.



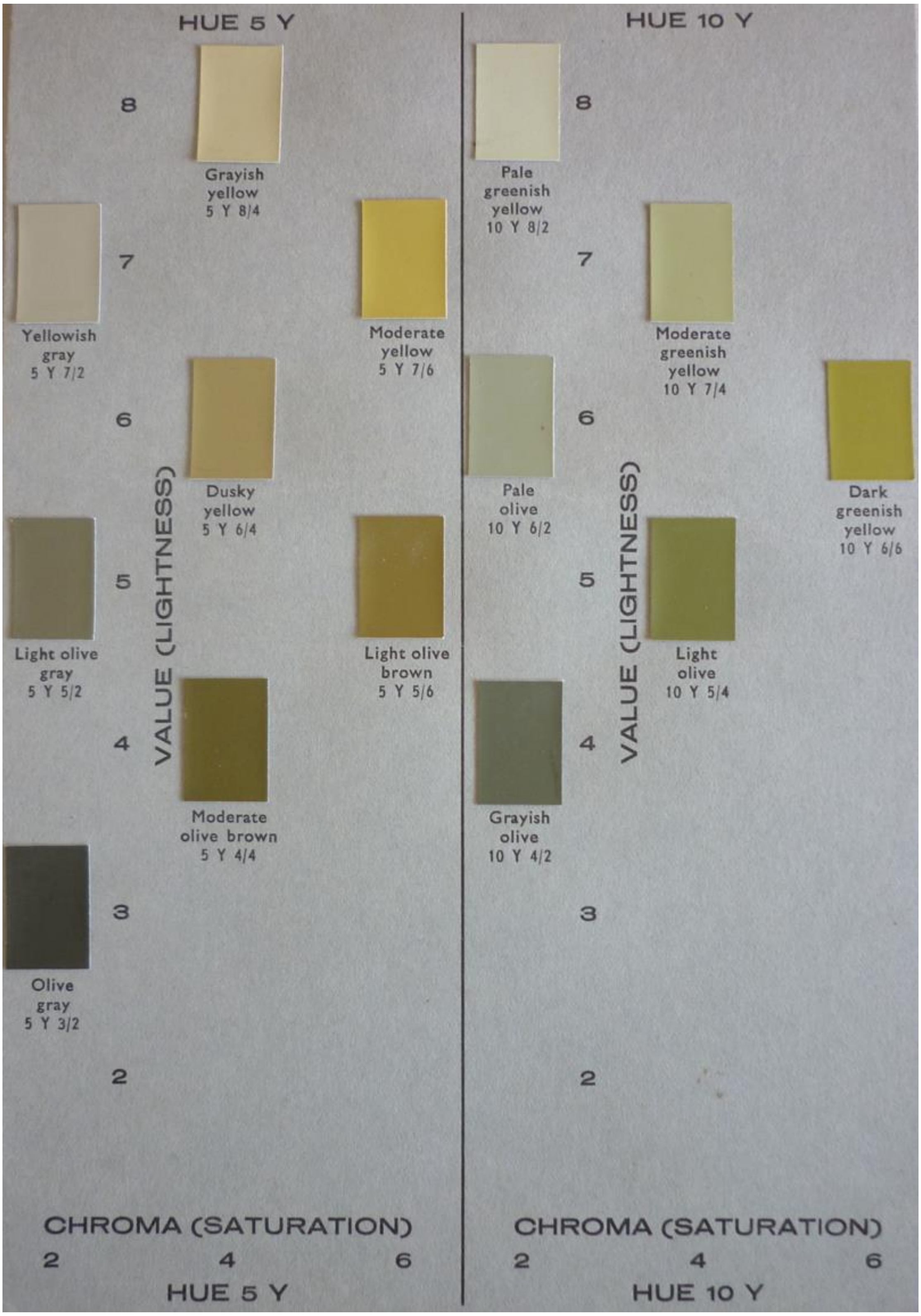


Representative photos of heterolithic bedding.
L-Linsen bedding, F-Flaser bedding, W-Wavy bedding.

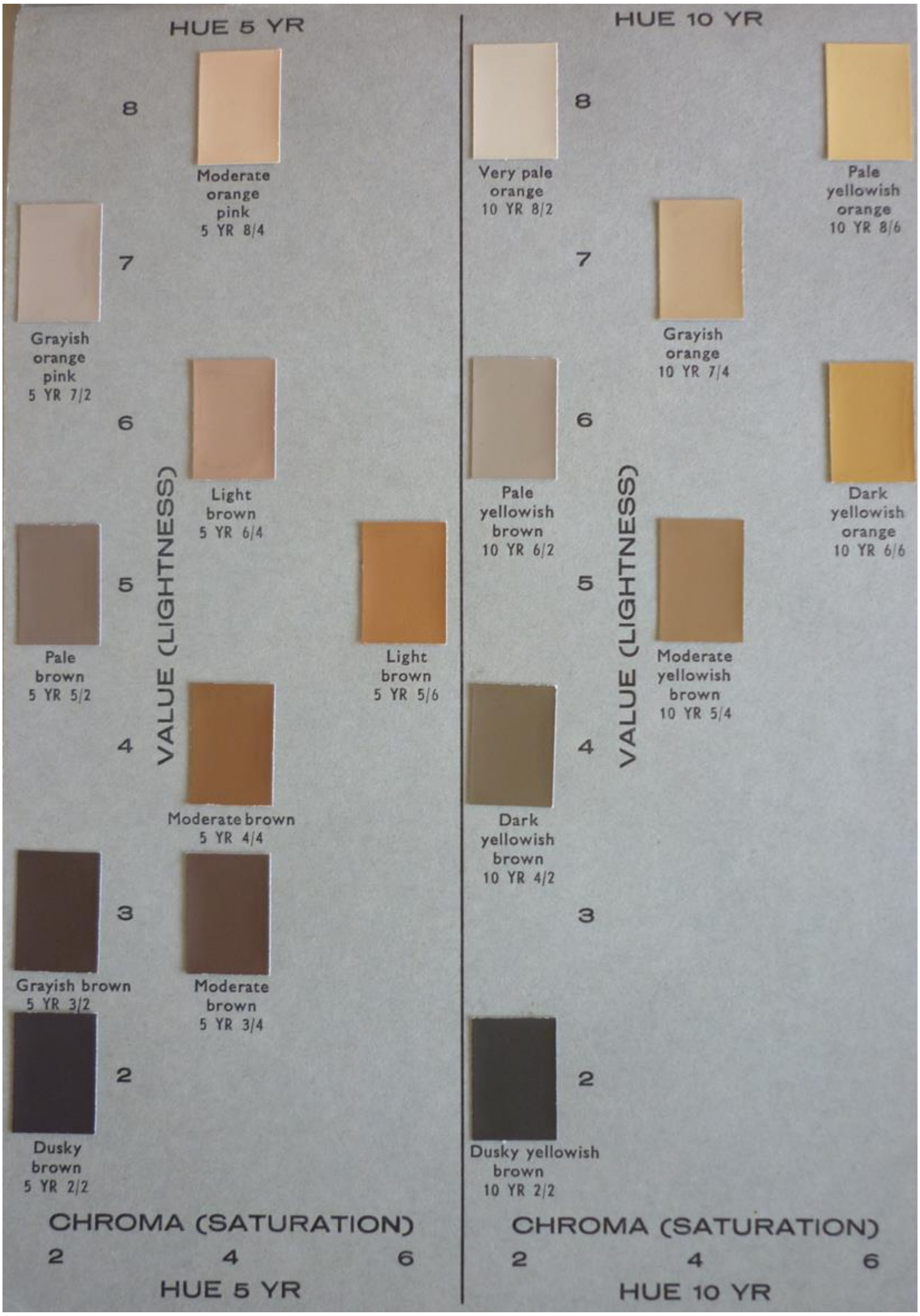
Appendix C4. Goddard Rock Colour Chart 1



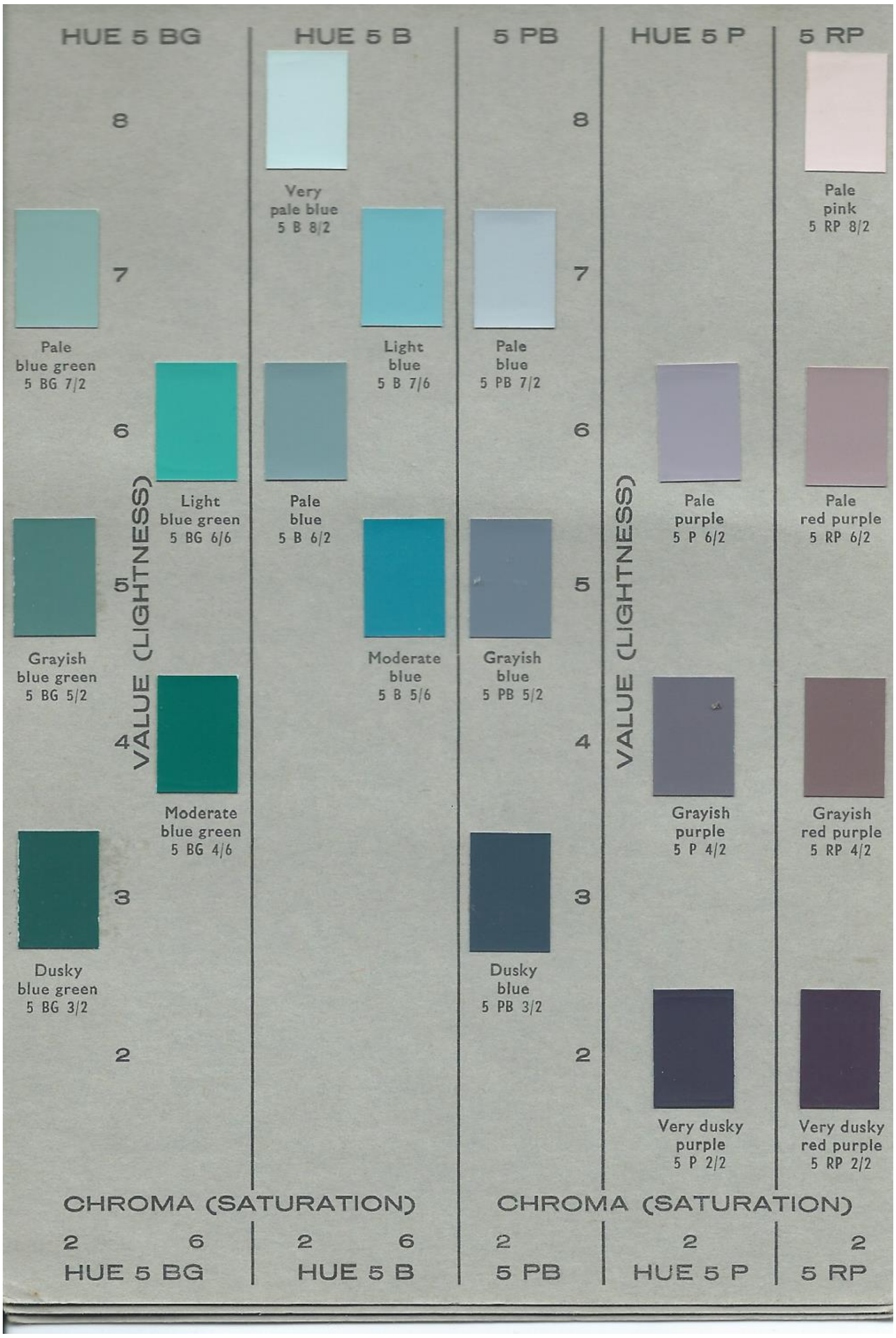
Appendix C4. Goddard Rock Colour Chart 2



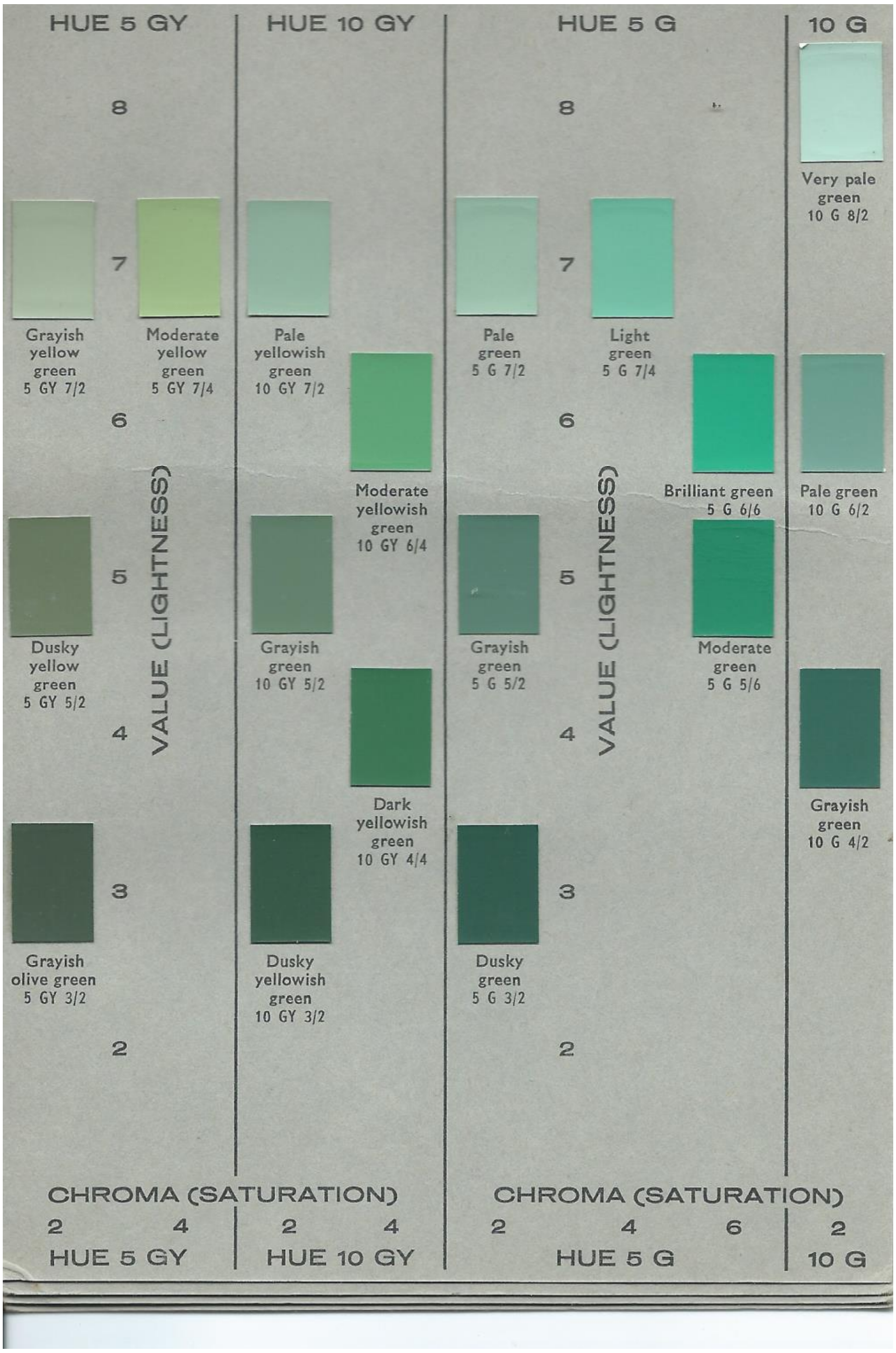
Appendix C4. Goddard Rock Colour Chart 3



Appendix C4. Goddard Rock Colour Chart 4



Appendix C4. Goddard Rock Colour Chart 5



Appendix C5. Structural Geology

Bedding

This consists of layering which owes its origin to the original deposition of sediment on a horizontal or sloping surface. In ancient rock, it can be very difficult to identify original bedding with certainty.

Cleavage

This is a generally planar fabric which may be present in fine-grained sedimentary rock such as mudstones. It consists of very closely spaced layers giving the rock a slatey appearance. It is a product of compression during deformation that results in a preferred orientation of platy or elongate minerals, compositional layering or grain size variations. There are several types of cleavage including; Continuous/Penetrative, Spaced, Slatey and Crenulation.

Continuous or Penetrative Cleavage

This describes fine-grained rocks consisting of platy minerals evenly distributed in a preferred orientation. The cleavage planes are continuous on a large scale. Where present, this is the principal cleavage type in the study area.

Spaced Cleavage

This occurs in rocks with minerals that are not evenly distributed and as a result the rock forms discontinuous layers or lenses of different types of minerals.

Slaty Cleavage

This is defined as having 0.01 mm or less of space occurring between layers.

Crenulation Cleavage

This contains microlithons that were folded by a previous phase of deformation.

Joints

These are generally planar fractures across which there is no visible displacement though, when traced laterally they may grade into faults in which there has been relative movement.

Joints are often closely spaced and usually, two or three sets of closely spaced joints are developed in lithified rock depending on its location in relation to regional structural elements.

Joints can develop due to regional *tensional forces* which form perpendicular to forces tending to pull the rock apart or *shear forces* which are associated with forces tending to slide one rock mass past an adjacent rock mass. These situations can be generated as a by-product of regional tectonic forces, faulting, folding or due to unloading during uplift and un-roofing of an orogen.

Faults

These are fractures across which there has been relative movement. Usually, a shatter zone develops along the fault plane and this is composed of fault gouge or breccia derived from the grinding of the rocks on each block. Alternatively, fault zones can consist of smooth polished planar or undulating surfaces with little fault gouge.

Appendix C6. Discontinuity Characteristics and Descriptors

Table 1. Fracture/Bed/Layer Spacing Classification

Spacing	**Joint Spacing**	**Bed (Layer) Spacing**
<20mm	J1 Extremely closely Spaced	B1 Laminated
20-60mm	J2 Very closely Spaced	B2 Very Thinly Bedded
60-200mm	J3 Closely Spaced	B3 Thinly Bedded
200-400mm	J4 Closely to Medium Spaced	B4 Thin to Medium Bedded
400-600mm	J5 Medium Spaced 1	B5 Medium Bedded 1
600-800mm	J6 Medium Spaced 2	B6 Medium Bedded 2
800-1000mm	J7 Medium Spaced 3	B7 Medium Bedded 3
1000-2000mm	J8 Widely spaced	B8 Thickly Bedded
>2000mm	J9 Very widely spaced	B9 Very Thickly Bedded

Table 2. Fracture Moisture Content

M1 The fracture is dry, tight or filling (where present) is of sufficient density or composition to impede water flow. Water flow along fracture does not appear possible.

M2 The fracture is dry with no evidence of previous water flow. Water flow appears possible.

M3 The fracture is dry but shows evidence of water flow such as staining, leaching or vegetation.

M4 The fracture filling (where present) is damp, but no free water is present.

M5 The fracture shows seepage and is wet with occasional drops of water.

M6 The fracture emits continuous flow under pressure. Filling materials (where present) may show signs of leaching or piping.

M7 The fracture emits continuous flow under moderate to high pressure. Filling Material may be substantially washed out.

Table 3. Fracture Openness
O1 Tight No visible separation
O2 Slightly open <1mm
O3 Moderately open 1-3mm
O4 Open 3-10mm
O5 Moderately wide 10-30mm
O6 Wide >30mm

Table 4. Discontinuity Persistence
P1-Very low persistence <1m
P2-Low persistence 1-3m
P3-Medium persistence 3-10m
P4-High persistence 10-20m
P5-Very high persistence >20m

Table 5. Block Sizes (J/m^3)
Volumetric joint count in Joints/m^3
SJ1-Very large blocks <1
SJ2-Large blocks 1-3
SJ3-Medium-sized blocks 3-10
SJ4-Small blocks 10-30
SJ5-Very small blocks 30-60
SJ6-Crushed rock >60

Table 6. Block Sizes (mm)
S1-Very small <60mm
S2-Small 60-200mm
S3-Medium 200-300mm
S4-Large 300-600mm
S5-Very large 600-1000mm
S6-1000-2000mm

Table 7. Block Types (Dearman 1991)
T1-Polyhedral
T2-Tabular
T3-Prismatic
T4-Equidimensional
T5-Rhombohedral
T6-Columnar

Type of block	Jointing characteristics
Polyhedral blocks	Irregular jointing without arrangement into distinct sets, and of small joints.
Tabular blocks	One dominant set of parallel joints, for example bedding planes, with other non-persistent joints; thickness of blocks much less than length or width.
Prismatic blocks	Two dominant sets of joints, approximately orthogonal and parallel, with a third irregular set; thickness of blocks much less than length or width.
Equidimensional blocks	Three dominant sets of joints, approximately orthogonal, with occasional irregular joints, giving equidimensional blocks.
Rhomboidal blocks	Three (or more) dominant mutually oblique sets of joints, giving oblique-shaped, equidimensional blocks.
Columnar blocks	Several, - usually more than three, - sets of continuous, parallel joints; length much greater than other dimensions.

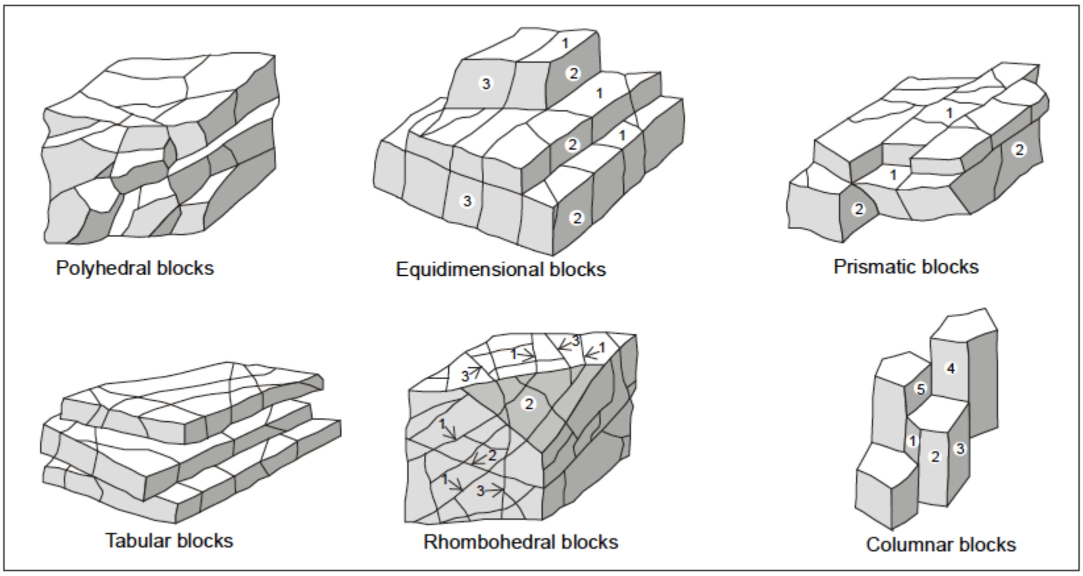
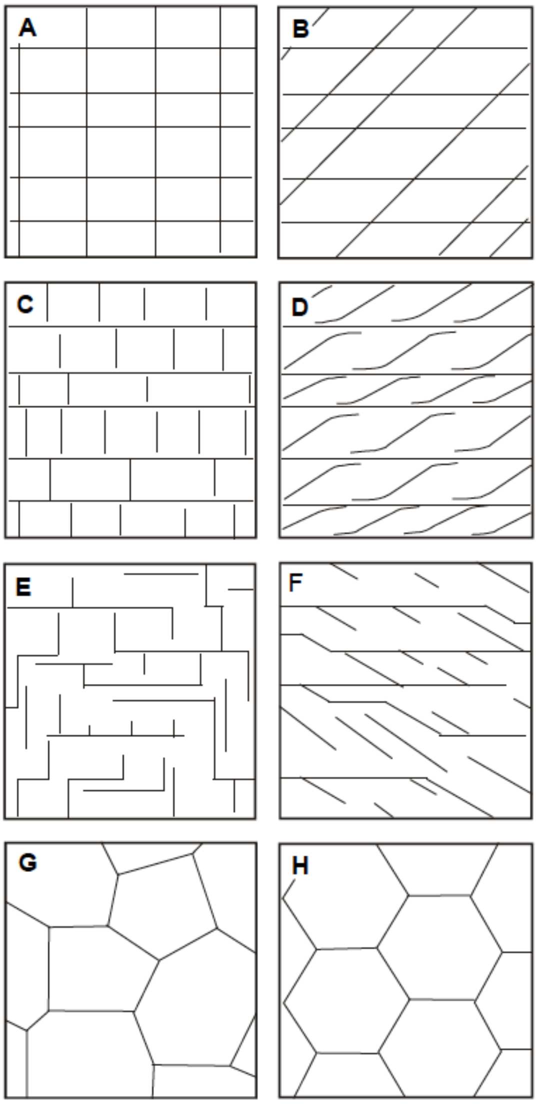


Table 8. Joint Patterns



A. Orthogonal pattern, with persistent sets (+ intersection)

B. Non-orthogonal pattern, with persistent sets (X intersections)

C. Orthogonal pattern, one set is persistent (T intersections)

D. Non-orthogonal pattern, one set with persistent joints

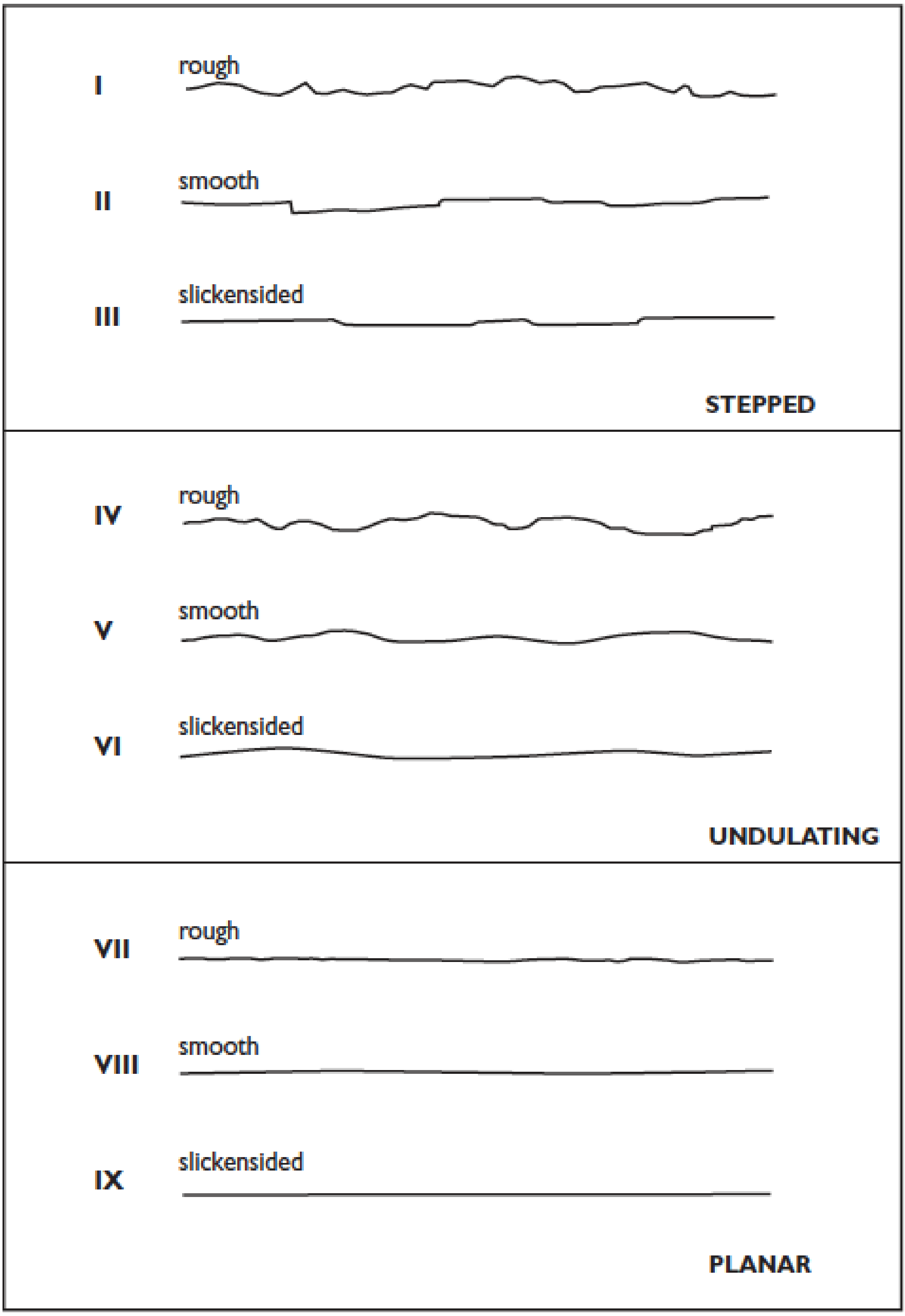
E. Orthogonal pattern, both sets have mainly discontinuous joints

F. Non-orthogonal pattern, both sets have mainly discontinuous joints

G. Triple intersections with all joints

H. Tripple intersections with 120° angles

Table 9. Joint Plane Form



Appendix C7. Strength of intact rock

<table>
<tr><th>Term</th><th>Field Identification of Specimen</th><th>Unconfined uniaxial compressive strength q_u (MPa)</th><th>Point load strength $I_{s(50)}$ (MPa)</th></tr>
<tr><td>Extremely strong</td><td>Can only be chipped with geological hammer</td><td>> 250</td><td>>10</td></tr>
<tr><td>Very strong</td><td>Requires many blows of geological hammer to break it</td><td>100 – 250</td><td>5 – 10</td></tr>
<tr><td>Strong</td><td>Requires more than one blow of geological hammer to fracture it</td><td>50 – 100</td><td>2 – 5</td></tr>
<tr><td>Moderately strong</td><td>Cannot be scraped or peeled with a pocket knife. Can be fractured with single firm blow of geological hammer</td><td>20 – 50</td><td>1 – 2</td></tr>
<tr><td>Weak</td><td>Can be peeled by a pocket knife with difficulty. Shallow indentations made by firm blow with point of geological hammer</td><td>5 – 20</td><td rowspan="3"><1</td></tr>
<tr><td>Very weak</td><td>Crumbles under firm blows with point of geological hammer. Can be peeled by a pocket knife</td><td>1 – 5</td></tr>
<tr><td>Extremely weak (also needs additional description in soil terminology)</td><td>Indented by thumb nail or other lesser strength terms used for soils</td><td><1</td></tr>
<tr><td colspan="4">Note: No correlation is implied between q_u and $I_{s(50)}$</td></tr>
</table>

Appendix C8. Classification of Weathered Rock

W1 Fresh, W2 Slightly Weathered, W3 Moderately Weathered, W4 Highly Weathered, W5 Completely Weathered, W6 Residual soil

Term	Grade	Abbreviation	Description
Unweathered (fresh)	I	UW	Rock mass shows no loss of strength, discolouration or other effects due to weathering. There may be slight discolouration on major rock mass defect surfaces or on clasts.
Slightly Weathered	II	SW	The rock mass is not significantly weaker than when unweathered. Rock may be discoloured along defects, some of which may have been opened slightly.
Moderately Weathered	III	MW	The rock mass is significantly weaker than the fresh rock and part of the rock mass may have been changed to a soil. Rock material may be discoloured, and defect and clast surfaces will have a greater discolouration, which also penetrates slightly into the rock material. Increase in density of defects due to physical disintegration process such as slaking, stress relief, thermal expansion/contraction and freeze/thaw.
Highly Weathered	IV	HW	Most of the original rock mass strength is lost. Material is discoloured and more than half the mass is changed to a soil by chemical decomposition or disintegration (increase in density of defects/fractures). Decomposition adjacent to defects and at the surface of clasts penetrates deeply into the rock material. Lithorelicts or corestones of unweathered or slightly weathered rock may be present.
Completely Weathered	V	CW	Original rock strength is lost and the rock mass changed to a soil either by chemical decomposition (with some rock fabric preserved) or by physical disintegration.
Residual Soil	VI	RS	Rock is completely changed to a soil with the original fabric destroyed.