HS2

C861

Summary assessment of ground conditions for Whitmore Heath Tunnel

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P01	James Ardern / Stewart Jarvis	25/06/2018	Information
P02	Gurjeet Singh Chana/Stewart Jarvis	09/02/2019	Updated using Final Ground Investigation Report information.
P03	Alan Phear	16/10/2019	Further Update

Security classification: OFFICIAL

Contents

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1 Summary

1.1.1 This report presents the geological setting (ground conditions) of the Whitmore Heath area based on desk study data, a summary of ground investigation data and a summary assessment of the proposed Whitmore Heath tunnel based on the interpreted ground conditions.

1.1.2 Between April and June 2018, a total of ten boreholes were completed at locations across Whitmore Heath to verify ground conditions in support of the desk-based evaluation of the preliminary design of the Whitmore Heath tunnel. Data was also gathered from in-situ strength testing, downhole geophysics, permeability testing, groundwater monitoring and laboratory testing of samples recovered from the ground.

1.1.3 The geology encountered at Whitmore Heath comprises the Chester Formation (with Pebble Beds). Typically, the ground profile was confirmed to comprise a weathered bedrock zone typically 5-10m in depth, overlying extremely weak to weak rock. Some superficial deposits were also encountered, but these are limited in occurrence both in their vertical and lateral extent. Groundwater levels measured thus far are below the proposed tunnel level.

1.1.4 This assessment of the findings from the ground investigation at Whitmore Heath have not altered the assumptions on ground or groundwater conditions based on the original desk study assessment which informed the initial preliminary design of the Whitmore Heath tunnel.

2 Introduction

2.1.1 The Proposed Scheme at Whitmore Heath includes two bored tunnels with associated tunnel portals at either end. The tunnels extend from a location just to the south of the A53 to the west of Whitmore Heath, passing below Whitmore Heath as shown in the plan in Figure 1. The tunnel works comprise:

- Southern Porous Portal, 150m long, Chainage 231+650 to Chainage 231+800;
- Separated twin bored tunnels for up and down line individually, 1, 112m long, Chainage 231+800 to Chainage 232+912; and
- Northern Porous Portal, 150m long, Chainage 232+912 to Chainage 233+062.

2.1.2 This report provides an assessment of the ground conditions at Whitmore Heath supported by desk-based assessment of the geological setting as well as the findings from the ground investigation undertaken in the area. The ground investigation was designed to assess ground and ground water conditions to:

- confirm previous assumptions on ground conditions made for the initial preliminary design phase considered in the deposited scheme.
- confirm the ground and groundwater conditions that inform the preliminary design stage of the tunnels in the Whitmore Heath area.

2.1.3 The residential properties located along the alignment of the tunnel are located approximately 30 m above the proposed tunnels.

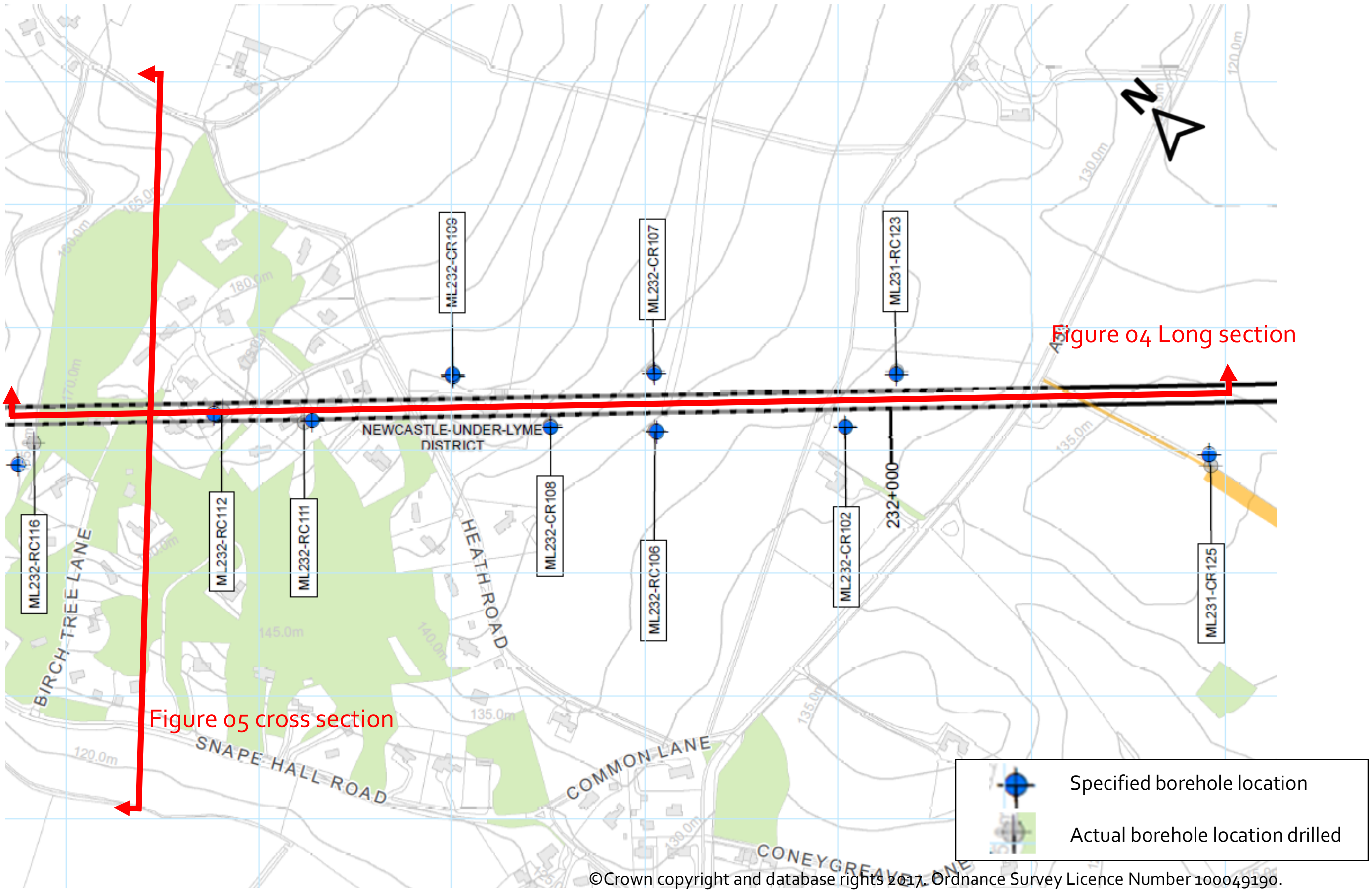


Figure 1 Borehole Location Plan and location of cross sections

3 Desk based assessment

3.1 Topography

3.1.1 The topography along the proposed route at Whitmore Heath (Chainage 232+000 to 232+850), forms a ridge composed of the Chester Formation of the Sherwood Sandstone Group. Local elevations rise from 135 m above Ordnance Datum (mOD) in the south to a peak of 175 mOD (Chainage 232+700), before reducing back down to 140 mOD (Chainage 232+900).

3.1.2 Abandoned gravel pits (as detailed in Section 3.2 below), not clearly defined on ordnance survey but observed during site walk over, influence topography locally with steep slope edges to the pits. However, these are localised relatively shallow features compared to the depth of the tunnel and unlikely to influence assessment.

3.2 Historical Land Use

3.2.1 Historical plans (1:2500 and 1:10000) have been reviewed for Whitmore Heath with respect to former land uses that could potentially impact on the Proposed Scheme design.

3.2.2 There is evidence on published historical mapping of numerous pits for extracting marl or sand and gravel over a number of years which is summarised in Figure 2 below. It appears that these quarries were 'open cast' rather than mined. Due to the nature of the Sherwood Sandstone, the presence of mapped 'sand and gravel' quarries/pits (rather than 'rock' quarries in the area) links to the anticipated weak and friable nature of the rock when excavated (covered later in this report), particularly over shallow weathered sections of bedrock close to the surface.

3.2.3 Ordnance Survey mapping suggests (given the contours do not reflect the quarried areas shown on Figure 2) that the quarries features were backfilled, perhaps as part of the residential development of the Whitmore Heath area. However, a site inspection has identified that some of the quarry areas were not completely backfilled and some features can be identified, be it that they are now are covered in vegetation.

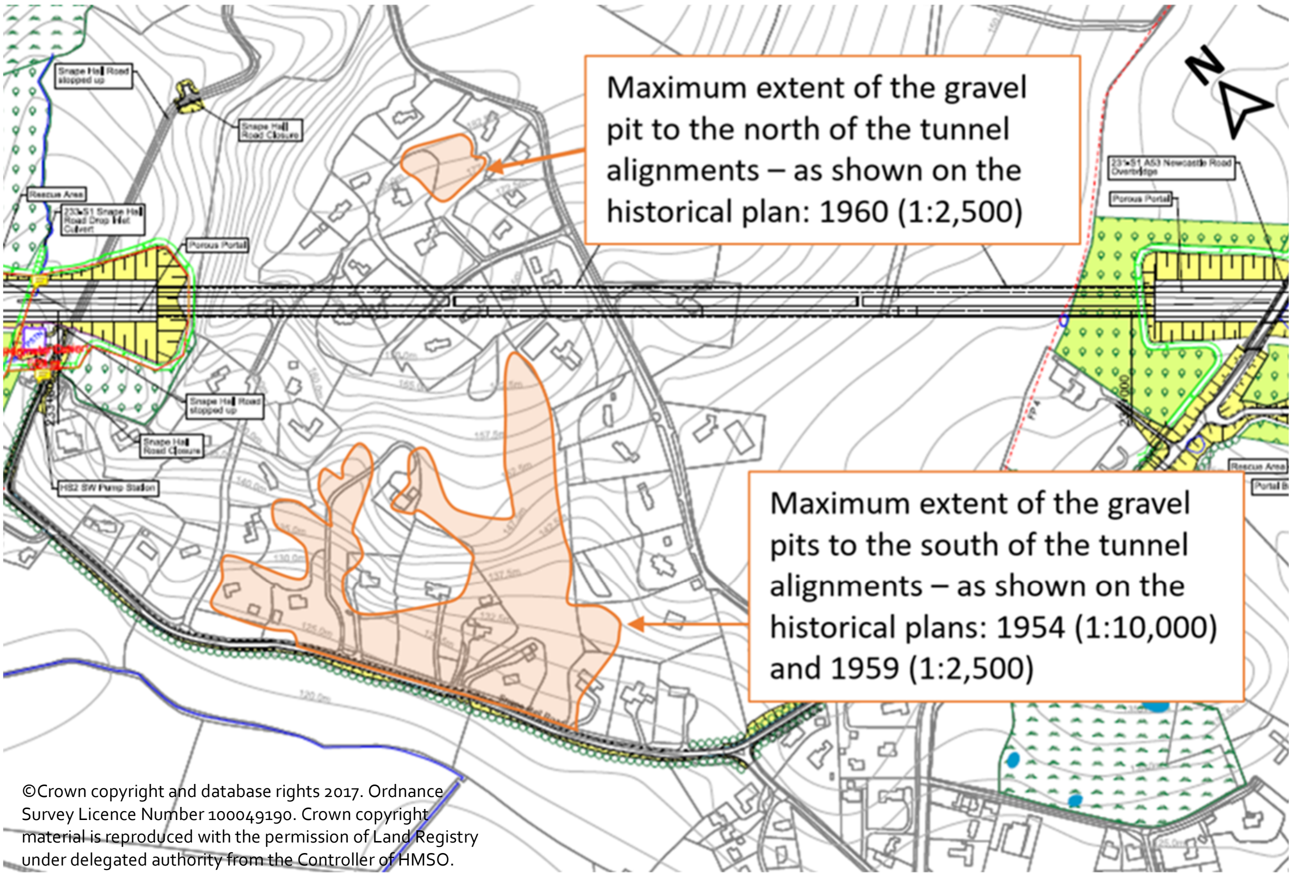


Figure 2 Approximate extent of Gravel Extraction activity at Whitmore Heath based on Ordnance Survey Maps

3.3 Geology and Groundwater Conditions

Geological Mapping

3.3.1 The British Geological Survey (BGS) geological mapping sheets, 1: 10,000 Series form the basis for identifying the solid geology underlying the Whitmore Heath area. The area is covered by several map sheets. An extract from the available BGS geological mapping for the Whitmore Heath area including a key is shown in Figure 3.

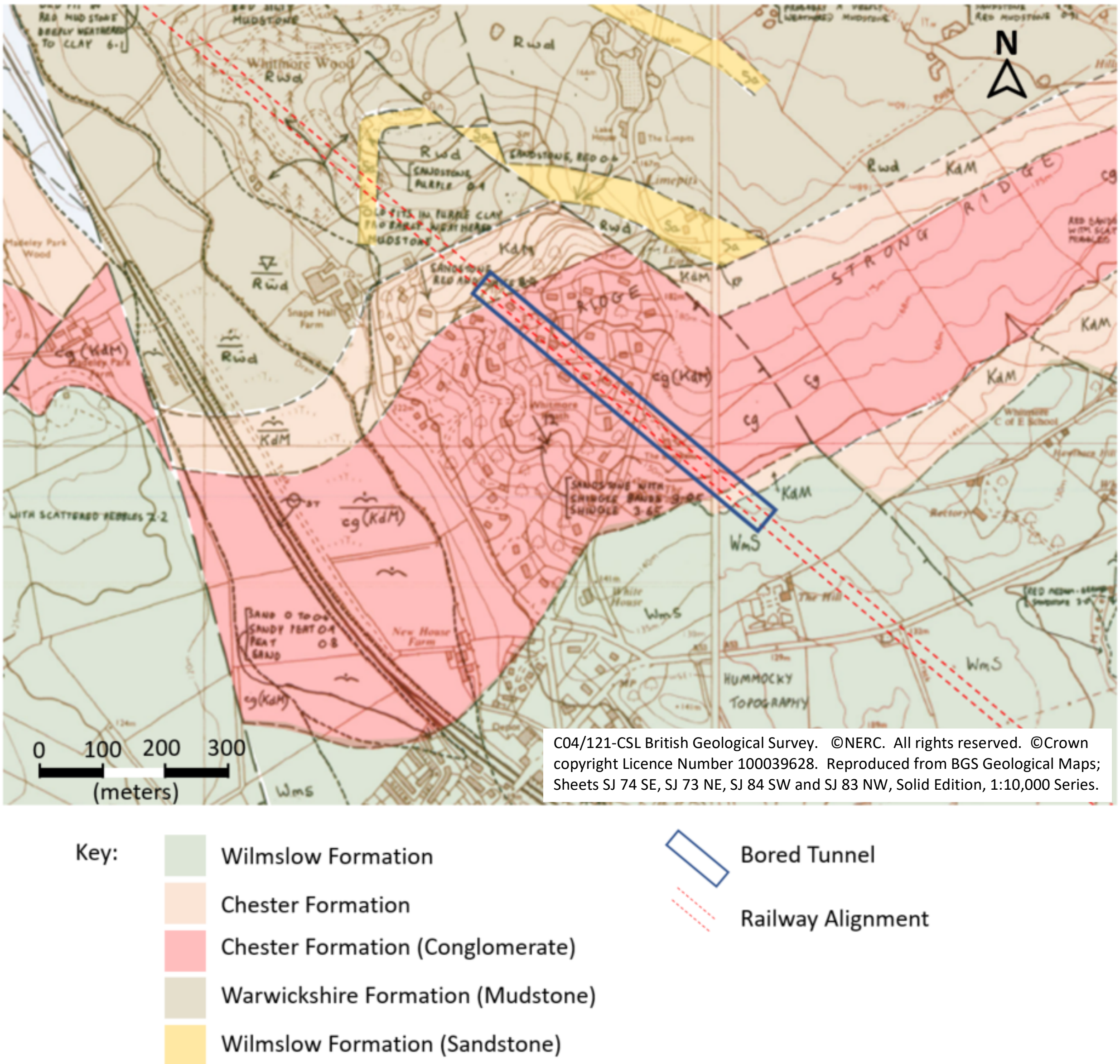


Figure 3 Combined extracts taken from the BGS Geological Map 1:10,000 series (based on Sheets; SJ 74 SE, SJ 73 NE, SJ 84 SW and SJ 83 NW) for the Whitmore Heath area.

Superficial Geology

3.3.2 Published information indicates limited occurrence of 'superficial' deposits across the Whitmore Heath location. Where present natural deposits will likely only be 2 – 3 m thick.

3.3.3 As discussed previously the historical development of the site may have resulted in some 'made ground' associated with open cast quarrying and or backfilling of open cast mines may be present across the site. Depths cannot be estimated from desk study assessment. These materials appear to be off the line of the proposed tunnels.

Solid Geology

3.3.4 Due to a lack of mapped superficial deposits at Whitmore Heath, the solid geology is anticipated to be encountered at shallow depth (below the topsoil). At Whitmore Heath the BGS maps identify that the Wilmslow and Chester Formations of the Sherwood Sandstone Group underlay the site as shown in Figure 2 above.

3.3.5 These two formations are described as alternating bands of Sandstone, Mudstone and some Conglomeratic Formations that dip to the south east. The Wilmslow Formation lies above the Chester Formation and due to the structural dip of the beds is only present at the southern end of the tunnel where it outcrops at the surface (from approximately Ch 231+825 to Ch 232+500). The Wilmslow Formation becomes thinner heading northwards along the route. The Wilmslow Formation typically contains fewer pebbly sandstones and conglomerates than the Chester Formation.

3.3.6 The British Geological Survey Memoir, Geology of the country around Stoke-on-Trent, notes that the boundary between the Wilmslow and the Chester Formation is often poorly defined and is often taken to be when at least a 20m thick sandstone layer, with rare pebbles occurrence, is observed overlying the pebbly sandstones of the Chester 'Pebble' Beds.

3.3.7 The Chester Formation is indicated to be ~150 m thick (confirmed from LNW Railway Whitmore Boreholes SJ 74 SW7, SJ 73 SE8 and SJ74 SE9). It mainly comprises a sandstone and conglomerate outcropping at the ground surface over the majority of the Whitmore Heath area.

3.3.8 Underlying the Chester Formation is the Warwickshire Group, predominantly Mudstone but may also feature some substantial sandstone bands. It is shown to outcrop within the northern end of the Whitmore Heath area but outside the section in tunnel.

3.3.9 The Wilmslow and Chester Formations have been affected by progressive weathering, the depth and degree of weathering of the rock will therefore vary along the route. Generally, the upper 5m to 10m of material is weathered to a residual soil i.e. to a sand and gravel consistency.

3.3.10 The Sherwood Sandstone Group is generally documented in published papers to have a lack of discontinuities or fractures in situ although occasional discontinuities could be anticipated.

3.3.11 A northwest to southeast trending fault is shown on the geological maps at approximately 200 m to the east of the tunnel alignment. The fault is downthrown to the southwest. Further faulting is present in the surrounding area due to past regional tectonic activity.

Published Data on the Sherwood Sandstone Group

3.3.12 The Sherwood Sandstone Group is present across much of the UK and has been encountered during numerous site investigations and civil engineering works leading to a good understanding of its engineering properties. It is widely reported in published papers (e.g. Buist and Thompson) that obtaining representative samples using traditional site investigation drilling is extremely difficult due to the weak cementation holding the material together. This results in the rock breaking down as a result of the drilling process, making sample recovery at times poor and/or unrepresentative of the in situ rock mass.

Previous Ground Investigation data in the Public Domain

3.3.13 A historic borehole record, drilled at the nearby to Whitmore Heath (reference location 'The Rectory') has been obtained from the BGS database. The date of the borehole is unclear but does not meet current logging standards. The log has been reviewed and although it is lacking in detail it reports the presence of Sandstones and Conglomerates from shallow depth, suggesting the borehole was logged as encountering a rock deposit rather than soil even though the recovery was reported as sand and gravel. The borehole was drilled using a rock roller drill bit with air flush which recovers completely disturbed samples (drill cuttings only).

3.3.14 Published ground investigation data for the Sherwood Sandstone Group reports Unconfined Compressive Strengths from laboratory testing of suitably recovered rock samples to be in the range of 0.5 to 5 MPa (Yates 1992). This equates to a rock described as having very weak and weak rock strength, which is consistent with Arup's own project experience.

Hydrogeological setting

3.3.15 Several springs are present in the area associated with the Sherwood Sandstone.

3.3.16 The Sherwood Sandstone is at the surface for much of this section, and forms part of a regional aquifer that is abstracted for water supply. There are several important abstraction *Sites* (pumping stations) and a scatter of Environment Agency (EA) observation boreholes. These observation boreholes record mean groundwater levels at elevations between 99.0 m OD and 108 m OD. The groundwater is therefore anticipated at a depth of 20 – 70 m below surface level at Whitmore Heath.

3.3.17 It is noted that the indicated groundwater elevation (108 m OD) closely corresponds with the base of a nearby valley (Meece Valley), suggesting that the elevation of the groundwater within the Sherwood Sandstone is locally controlled by the topography.

4 Ground Investigation

4.1 Outline of investigation

4.1.1 Ground Investigation has been completed at Whitmore Heath with ten boreholes been completed and logged. The depths of these boreholes range from 43 m to 85 m. The approximate positions are shown on the location plan in Figure 1 and includes the borehole references.

4.1.2 The preliminary ground investigation has been designed to provide good quality information regarding ground conditions at intervals along the proposed tunnel route. The investigation has comprised rotary core drilling, drilling parameter measurement, in-situ testing and geophysical logging of the borehole walls.

4.1.3 Samples recovered from the ground have been subjected to laboratory testing and results obtained. In-situ testing and geophysical logging carried out in the boreholes has been processed and submitted. All Engineer's Logs have been completed taking into consideration the driller's logs, desk based geological setting and supporting test data.

4.1.4 Groundwater monitoring installations have been constructed in some boreholes to allow for the monitoring of groundwater levels.

4.1.5 The information gained is intended inform preliminary design options to be developed and to support the choice of tunnelling method and is not intended to meet detailed design requirements.

4.2 Summary of findings of the fieldwork

4.2.1 The geological sequence and ground conditions are generally as anticipated (based on the desk study data). Sandstones, conglomerates and mudstones belonging to the Wilmslow Formation and Chester Formation were encountered from shallow depths. Conditions typically comprise a weathered section of bedrock over extremely weak to weak rock.

4.2.2 Shallow superficial deposits encountered were scattered and thin. No significant depths of made ground were encountered.

4.2.3 The Whitmore Heath topography, geological and groundwater profile based on the 2018 ground investigation findings (supported by desk study data) and tunnel alignment are shown on the cross section included as Figure 4[1]. Figure 5 shows an

[1] note there is a varying horizontal and vertical scales to the cross section in Figure 4 due to the length of section and the need for clarity of the data reported

illustrative cross section perpendicular to the tunnel across Whitmore Heath. Figure 5 is at the same horizontal and vertical scale and is also therefore representative of illustrative variation in topography west to east and the tunnel in cross section. The ground conditions illustrated on Figure 5 combine Borehole ML232-RC112 with desk based assessed anticipated ground conditions.

4.2.4 The geological formations encountered, and early assessment of ground water level are summarised below.

Wilmslow Sandstone Formation

4.2.5 The Wilmslow Sandstone Formation was encountered in boreholes ML231-RC123 and ML232-CR102, between Chainage 231+700 to 232+250. As shown in Figure 4 this formation underlies the site at ground surface over the southern tunnel portal section to the south of Whitmore Heath. A weathered layer was encountered at the top of the Wilmslow Sandstone Formation. This commonly comprised residual sands and gravels with varying cobble content and occasionally clay was present. The weathered layer was present to a depth of between 6.5 and 11.5 m below ground level.

4.2.6 Below the upper weathered zone (6.5-11.5 mbgl), the Wilmslow Formation comprised extremely weak to very weak Sandstone. Mica was frequently present within the sandstone.

4.2.7 The base of the Wilmslow Formation was poorly defined.

Chester Formation

4.2.8 The Chester Formation underlies the Whitmore Heath area at ground surface over the length of the tunnel alignment as shown in Figure 4 and Figure 5. The Chester formation was encountered in boreholes: ML231-RC123, ML232-CR102, ML232-CR106, ML232-CR107, ML232-CR108, ML232-RC111 and ML232-RC112.

4.2.9 The upper profile of the Chester Formation exhibits a weathered layer comprising residual sands and gravels with more competent material being encountered below. The weathered layer measures 3 – 4 m in thickness on top of Whitmore Heath (boreholes ML232-RC111 and ML232-RC112) with greater thicknesses measured down the eastern flank of Whitmore Heath, with the weathered layer measuring between 5 and 10 m (boreholes ML232-CR106, ML232-CR107, ML232-CR108).

4.2.10 The weathering in the Chester Formation is predominantly confined to an upper layer.

4.2.11 Below the weathered zone, the Chester Formation comprises very weak locally extremely weak Sandstone and Conglomerate. Mudstone beds were encountered infrequently. The base of the Chester Formation was not encountered in the investigation.

Warwickshire Formation

4.2.12 The Warwickshire Formation was encountered at the base of borehole ML232-CR106 and therefore underlies the Chester Formation over the majority of Whitmore Heath based on sequencing and geological setting. The Warwickshire Formation is likely to underlie the ground surface to the north of Whitmore Heath as shown in Figure 4 but this was not investigated in the recent ground investigation as it lies outside the main tunnel section (within the tunnel portal section).

Ground water

4.2.13 Groundwater level monitoring has been undertaken over a full cycle of seasons (12 months) from June 2018 to July 2019. Interpretation of groundwater data in this report reflects the period of monitoring June 2018 to January 2019 and interpretation will be reviewed following the further period of water level monitoring up to July 2019 to account for seasonal variations.

4.3 Geotechnical Properties

4.3.1 The geotechnical properties have been assessed using standardised laboratory testing.

4.3.2 In-situ tests (Standard Penetration Tests or SPT) in the weathered zone (upper section of the bedrock) indicate that the relative density of the granular material encountered is loose becoming dense with depth.

4.3.3 In-situ tests (SPT) for the sandstones of the Wilmslow and Chester Formations[2] indicate extremely weak material at shallow depths (immediately below the weathered zone) with a slight increase in strength with depth i.e. becoming very weak / weak strength in places. It is likely that some of the SPT's will have been detrimentally affected by the presence of cobbles. However, the results give an indication of the consistency (strength) of the materials present.

4.3.4 The in-situ testing and descriptions appears to suggest unconfined compressive strength similar to those encountered elsewhere in the Sherwood Sandstone Group in line with the desk study review and early assessment assumptions for the tunnel.

4.3.5 The borehole walls held up unsupported to facilitate geophysical testing of the borehole walls (in situ rock conditions). This testing supports the classification that this material is a weakly cemented rock below the weathered zone, which is difficult to confirm purely from sampling observations due to the nature of the rock. Occasional fractures of the rock mass have been observed in the core samples obtained (in borehole ML232-CR102a large joint was encountered) though only of

[2] applying correlations to SPT results for weak rock, based on Cole and Stroud (1976)

limited vertical thickness. This is as expected from desk study although the quality of sampling of the material may influence joint and fracture observations. The large joint in ML232-CR102a was observed in situ with the geophysics televiewer. The televiewer also confirmed generally a 'massive' (infrequent joints) formation in line with the desk based geological setting review.

4.4 Tunnelling Assessment Informed by Ground Conditions

4.4.1 Both Figures 4 and 5 give a clear illustrative representation of the ground conditions influencing the tunnel assessment. The elevation of the crown ranges between approximately 124 to 134m OD (a minimum of 30m below ground surface) and the invert elevation ranges between 114 to 124m OD, between Chainage 231+800 and Chainage 232+912. The ground conditions encountered across this interval (in boreholes ML232-RC106, ML232-CR107, ML232-RC111 and ML232-RC112) comprise extremely to very weak sandstone and or conglomerate rock from 5-10m below the ground surface to a depth of 20 to 30 m below the invert of the tunnel.

4.4.2 Assessment of the ground and groundwater conditions confirms the initial preliminary design phase assumptions with respect to tunnel construction methodology and dewatering. The ground conditions at Whitmore Heath over the depth influenced by the tunnel were confirmed in the ground investigation to be a weakly cemented rock with conglomerate and a 'massive' (infrequent joints) formation. The ground behaviour for tunnel assessment is therefore not governed by rock joints. The tunnel assessment has assumed 'soft ground' conditions to ensure that worse case scenarios have been considered in the analysis undertaken. The assumptions made in the tunnel assessment at preliminary design stage with respect to ground conditions remain valid and conservative following a review of the Ground Investigation results. The geology was assumed to be a weak rock like mass structure with gravel pockets. The rock is anticipated to have a sand like structure when disturbed.

4.4.3 Requirements for dewatering during tunnel installation are unlikely based on ground water monitoring data collected to date (over the June 2018 to Jan 2019 period).

4.4.4 The ground conditions confirm that a range of options could be adopted for the construction of the proposed tunnels. The AP2 design for the Whitmore Heath Tunnel includes a 1,112 m long twin bored tunnel. The tunnelling contractor will determine the method of construction to be adopted.

4.4.5 The tunnel requires cross passages to connect the twin tunnels. Cross passages will likely be excavated using mined tunnelling methodology.

4.4.6 The surface settlement analysis taking into consideration the residential properties located along the alignment of the tunnel (located 30 m above the proposed tunnel) remains valid and conservative based on the information provided by the 2018 ground investigation. Two different scenarios have been assessed based on likely tunnel construction methodology suitable for the ground conditions (TBM and Sprayed Concrete Lining).

4.4.7 The localised variation in topography due to the abandoned gravel pits does not influence the outcome of the tunnel design assessment due to the depth of the tunnel.

5 Glossary

5.1.1 Rotary Core Drilling – drilling technique utilising a rotary drilling rig to sample rock.

5.1.2 Permeability testing – laboratory or in situ test to measure the rate of fluid flow through the ground (soils and rocks).

5.1.3 Groundwater level monitoring – measurement of ground water levels in standpipes and piezometers that have been installed in a borehole.

5.1.4 Downhole geophysical (logging) – use of geophysical techniques to assess in situ rock properties

5.1.5 Televiewer - is tool lowered down the borehole to record images of the in situ ground conditions. Optical and acoustic versions commonly used.

5.1.6 Preliminary Engineer's Logs - the record of the soil and rock descriptions undertaken and include estimated relative density and strength data based on observations and in situ SPT. The logs have not been adjusted to reflect laboratory testing or geophysics.

5.1.7 Drillers Daily Records – records prepared by the driller for a borehole; records driller's assessment of ground, progress, in situ test results, groundwater observations and any other notable observations.

5.1.8 Glacial Till – glacial sediment deposit derived from the erosion and entrainment of material by the moving ice of a glacier.

5.1.9 Conglomerate - a coarse-grained sedimentary rock composed of rounded fragments embedded in a matrix of cementing material.

5.1.10 Micaceous - term used to describe a rock containing the mica, typically a shiny platy mineral.

5.1.11 Unconfined (Uniaxial) Compressive Strength - The maximum axial compressive strength of an unconfined sample of rock stress that a cylindrical sample of material can withstand before failing.

5.1.12 Point Load Test - Laboratory rock strength test.

5.1.13 Standard Penetration Test - in situ testing method used to determine the strength of subsurface ground.

5.1.14 Geological Fault – a planar fracture or discontinuity in a volume of rock, across which there has been significant displacement as a result of rock-mass movement.

5.1.15 Downthrow (with respect to a fault) - the side of a fault that appears to have moved downward relative to the other side.

5.1.16 Hydrogeology – the area of geology that deals with the distribution and movement of groundwater in soil and rocks

5.1.17 Weathering (of rock) - the breakdown of rocks by the action of rainwater, extremes of temperature, and biological activity. It does not involve the removal of rock material.

5.1.18 Geological Setting – geological conditions/features and expected physical behaviour of ground conditions of a geographic location determined from an understanding of geological deposition and processes.

6 Acronyms

6.1.1 BGS British Geological Survey

6.1.2 CA Community Area

6.1.3 GI Ground Investigation

6.1.4 mOD Metres (above) Ordnance Datum

6.1.5 MPa Mega Pascal

6.1.6 PLT Point Load Test.

6.1.7 TBM Tunnel Boring Machine

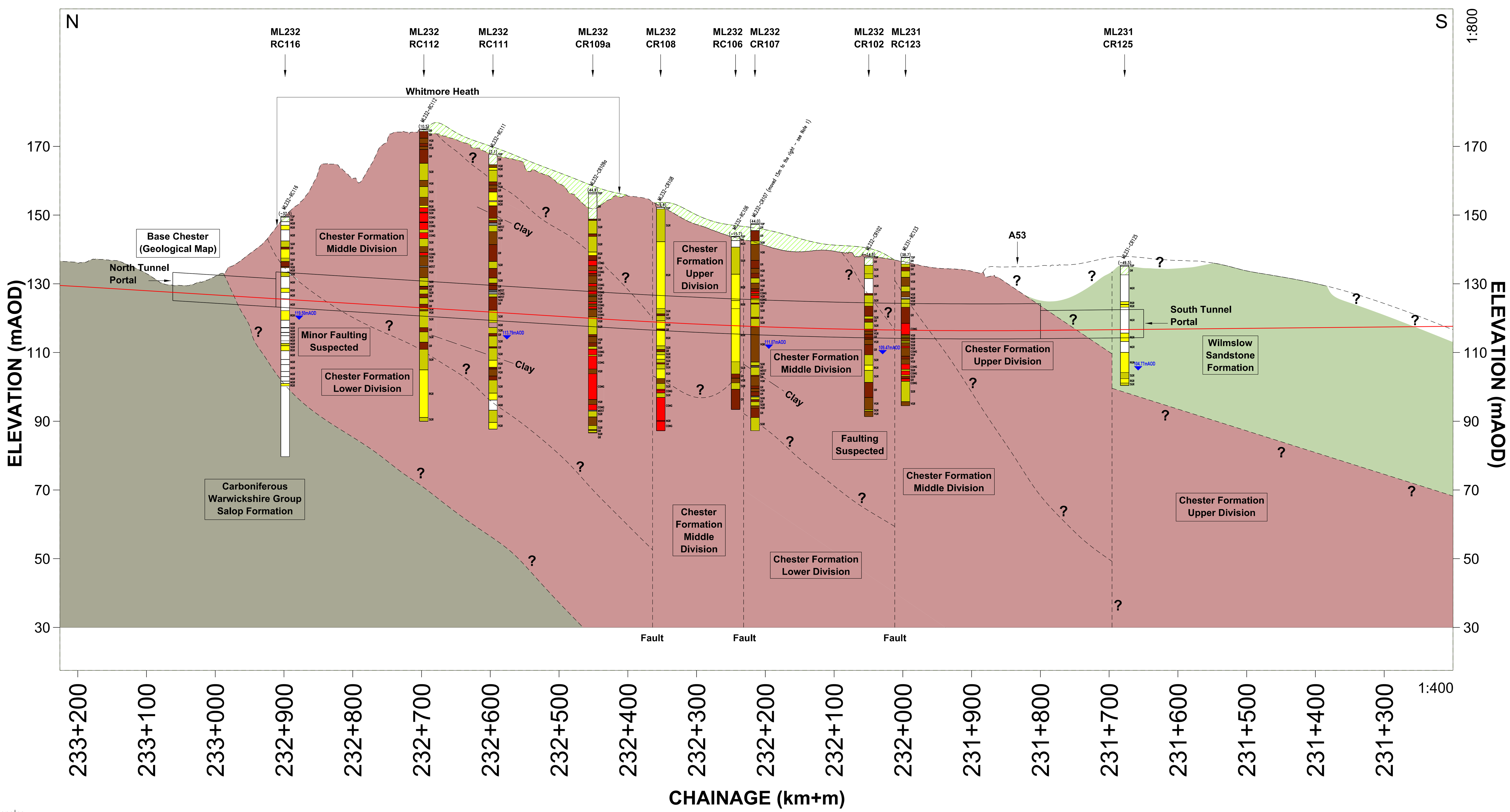
6.1.8 SPT Standard Penetration Test

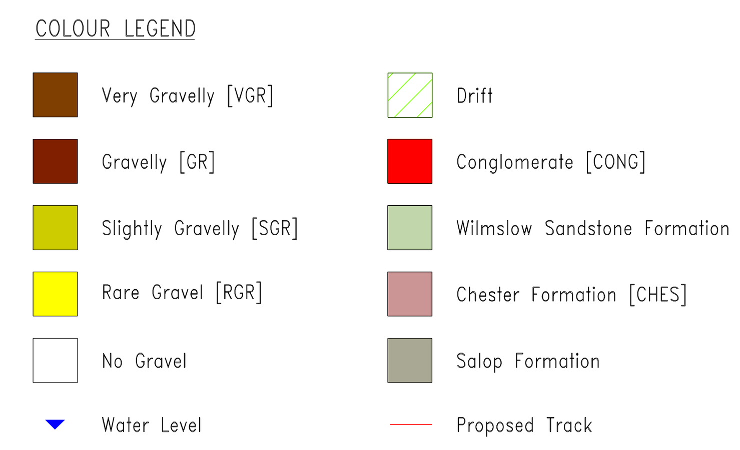
6.1.9 UCS Unconfined (Uniaxial) Compressive Strength.

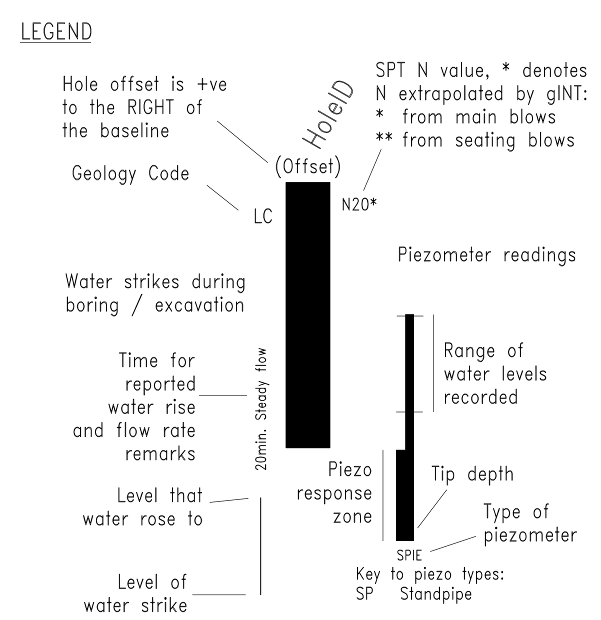
7 References

1. Historic OS Mapping Sheets at scale 1:10,000 (Year 1900, 1925, 1947, 1954, 1967, 1968, 1981 and 1982) and at scale (Year 1882, 1900, 1924, 1959, 1960 and 1980)
2. BGS Borehole at the Rectory (Borehole BGS ID: 792519 and BGS Reference: SJ84SW132)
3. British Geological Survey (BGS) geological mapping sheets, 1: 10,000 Series (Sheets SJ 74 SE, SJ 73 NE, SJ 84 SW and SJ 83 NW)

4. Sedimentology, Engineering Properties and Exploitation of the Pebble Beds in the Sherwood Sandstone Group (Lower Trias) of North Staffordshire, with Particular Reference to Highway Schemes by Buist and Thompson 1982
5. British Geological Survey, Geology of the country around Stoke-on-Trent, Memoir for 1: 50,000 Geological Sheet 123
6. K.W.Cole and M.A.Stroud, Rock socket piles at Coventry Point, Market Way, Coventry, Geotechnique, Volume 26 Issue 1, March 1976, pp. 47-62
7. P.G.Yates, The material strength of sandstones of the Sherwood Sandstone Group of the north Staffordshire with reference to microfabric, Quarterly journal of Engineering Geology (1992), Volume 25, p 107-113







Work-in-progress

Rev	Description	Drawn	Checked	Con App	HS2 App

Legends/Notes:
1. Borehole locations ML232-RC106 and ML232-CR107 are located at the same chainage, and are shown diagrammatically on this section.

HS2

Registered in England
Registration No. 06791686
Registered office:
2 Snow Hill, Queensway,
Birmingham, B4 6GA

Creator/Originator: Ove Arup & Partners International Ltd

Zone	Route Wide
Project/Contract	C861 Hybrid Bill Additional Provision 2 AP2
Design Stage	Hybrid Bill - Interim Preliminary Design AP2
Discipline/Function	Geotechnical
Drawing Title	Whitmore Preliminary Geological Section
Drawn	JSE
Checked	JN
Approved	DE
Date	12/12/2018
Scale	AS SHOWN
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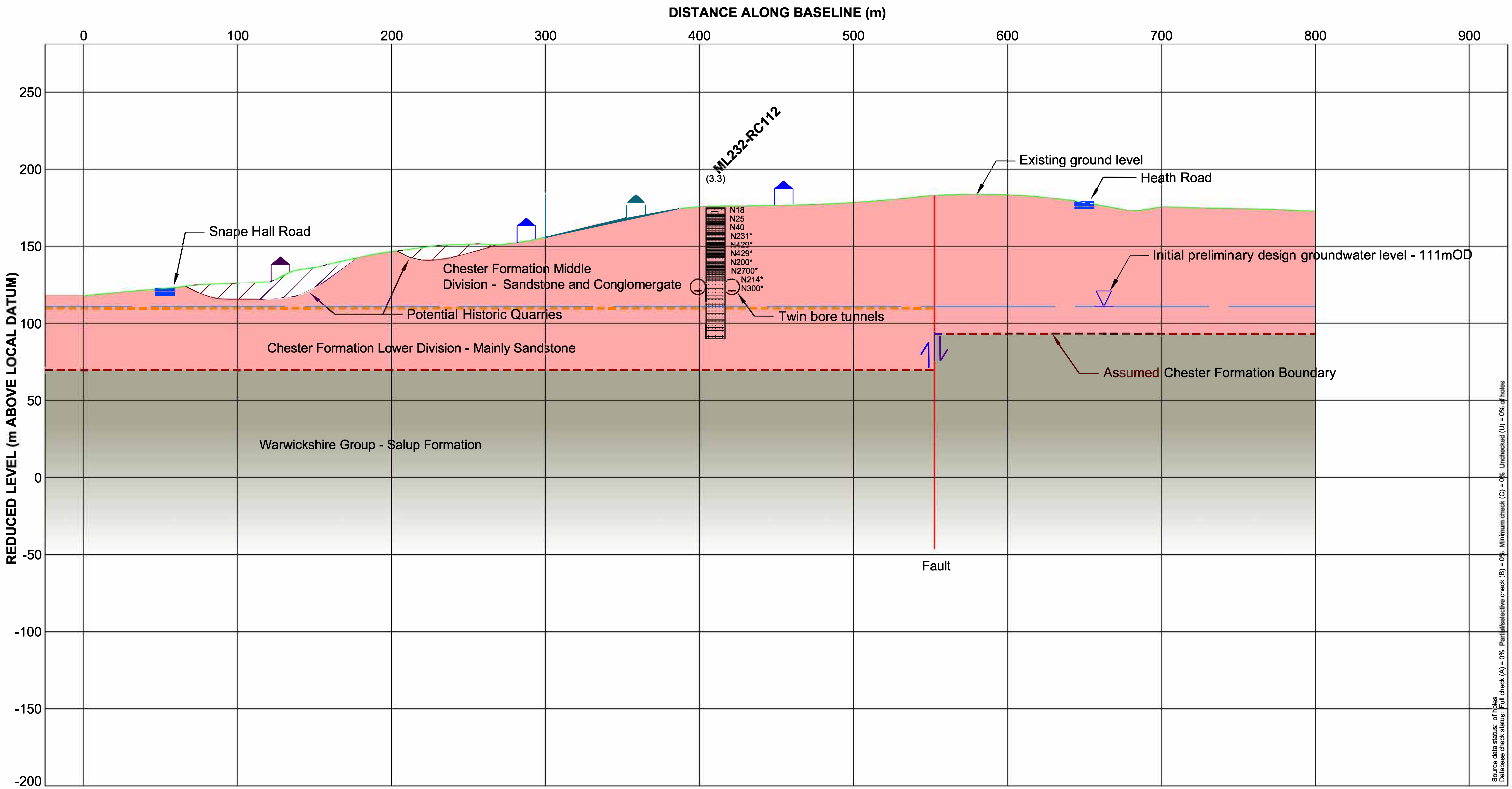
Rev.	P00.2



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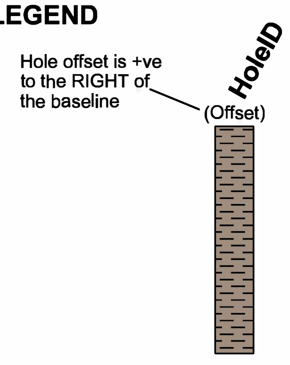
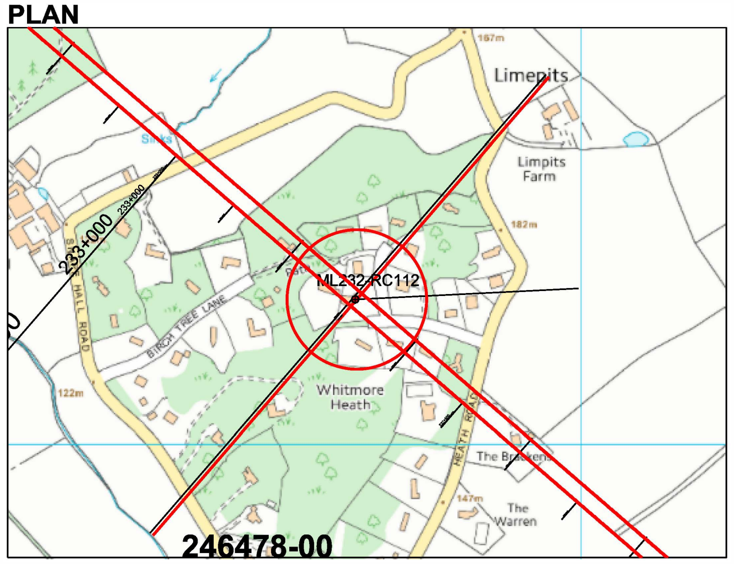
LEGEND



PLAN



1:10,000

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- ALLUVIUM [ALV]
- PEAT [PEAT]
- Peat [P]
- ORROLAND MEMBER [ORR]
- ORGANIC DEPOSITS [ORGD]
- [OKWDG]
- No recovery [NR]
- BOUNDARY BETWEEN LOWER AND MIDDLE CHESTER FORMATION
- WARWICKSHIRE BOUNDARY FORMATION
- GROUNDWATER LEVEL
- EXISTING GROUND LEVEL

HS2 PHASE 2A
GEOLOGICAL CROSS SECTION

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FIGURE 05

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